



Long Term Resource Monitoring Program

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Multiyear Synthesis of the Macroinvertebrate Component from 1992 to 2002 for the Long Term Resource Monitoring Program



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**Multiyear Synthesis of the Macroinvertebrate Component
from 1992 to 2002
for the Long Term Resource Monitoring Program**

by

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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiuse character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

This multiyear report supports Task 2.2.7 as specified in Goal 2, *Monitor Resource Change*, of the LTRMP Operating Plan (U.S. Fish and Wildlife Service 1993). This report was developed with funding provided by the LTRMP.

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Abstract: In 1992, macroinvertebrate sampling was begun in Pools 4, 8, 13, and 26; the Open River Reach of the Mississippi River; and La Grange Pool of the Illinois River as part of the Long Term Resource Monitoring Program. Long-term monitoring is needed to detect population trends and local changes in aquatic ecosystems. We selected mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and the exotic *Corbicula* species for monitoring. Midges (Chironomidae) were added to the sampling design in 1993 and zebra mussels (*Dreissena polymorpha*) were added in 1995. Sampling was based on a stratified random design and conducted at approximately 125 sites per study area. Mean densities of taxa were weighted by strata for extrapolation. The poolwide estimated mean densities of mayflies, fingernail clams, and midges were all within the range of variation observed historically. Over the last 11 years of sampling, the northern study areas supported the highest densities of the target organisms.

Key words: Benthic aquatic macroinvertebrates, *Corbicula*, fingernail clams (Pisidiidae), Illinois River, Long Term Resource Monitoring Program, mayflies (Ephemeroptera), midges (Chironomidae), Mississippi River, zebra mussels (*Dreissena polymorpha*)

Introduction

The Upper Mississippi River System (UMRS) is one of this Nation's unique natural resources. It encompasses the commercially navigable reaches of the Upper Mississippi River (UMR), as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. The ecosystem provides habitat to a wide array of fish and wildlife species distributed among a complex assortment of flowing channels, floodplain lakes, backwaters, wetlands, and floodplain forests (Patrick 1998). With an ecosystem as diverse and complex as the UMRS, many of its processes and their interrelationships are not well known. One way to help understand this multifaceted system is through environmental monitoring.

Macroinvertebrate monitoring by the Long Term Resource Monitoring Program (LTRMP) is intended to provide a better understanding of the conditions needed to support viable

macroinvertebrate populations at levels adequate for sustaining native fish and migrating waterfowl. Scientific nomenclature and common names are based on the Integrated Taxonomic Information System (<http://www.itis.usda.gov>). Mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and midges (Chironomidae)—part of the soft-sediment substrate fauna—were chosen as target organisms for the LTRMP because of their important ecological role in the UMRS, especially as a source of food for waterfowl and fish (Appendix A). Thompson (1973) found that in fall lesser scaup (*Aythya affinis*) gizzards contained 76% fingernail clams and about 13% mayflies. Thompson also found the target organisms to be important to canvasbacks (*A. valisneria*), ring-necked ducks (*A. collaris*), and American coots (*Fulica americana*) feeding in open water. The Waterfowl Management Handbook also discusses the importance of invertebrates to waterfowl (Eldridge 1988). Shorebirds and wading birds also consume large

numbers of invertebrates (Kushlan 1978). A number of fish, including commercial and sport fish such as crappies (*Pomoxis* spp.), shovelnose sturgeon (*Scaphirhynchus platyrhynchus*), walleye (*Stizostedion vitreum*), bluegill (*Lepomis macrochirus*), freshwater drum (*Aplodinotus grunniens*), and yellow perch (*Perca flavescens*) feed on the target organisms (Hoopes 1960; Jude 1968; Ranthum 1969; Tyson and Knight 2001).

The Asiatic clam (*Corbicula* spp.) and zebra mussel (*Dreissena polymorpha*; Appendix A), both non-native freshwater bivalves, were chosen for monitoring because of possible detrimental effects they may have on the economy and biology of the UMRS (Tucker 1995a,b; Effler et al. 1996; Haynes et al. 1999; Pimentel et al. 2000) and their status is of concern to river managers.

Researchers have traditionally used macroinvertebrates as biological indicators of river water quality (Fremling 1964, 1973, 1989; Myslinski and Ginsburg 1977; Rosenberg and Resh 1993; Steingraber and Weiner 1995). An indicator species can be defined as a species that has particular requirements with regard to a known set of physical or chemical parameters. Macroinvertebrates also perform an important ecological function by digesting organic material and recycling nutrients (Reice and Wohlenberg 1992).

Long-term monitoring of biological resources is at the core of understanding the dynamics of ecological patterns and processes and trying to separate variation due to natural and anthropogenic influences (<http://www.pwrc.usgs.gov/research/sis98/hammer8s.htm>). Few long-term studies on the distribution and abundance of macroinvertebrates in large rivers have been published (LaRoe et al. 1995). Several areas of the UMRS have been sampled sporadically for benthic macroinvertebrates by various researchers (Fremling 1964; Carlander et al. 1967; Gale 1969; Hubert et al. 1983; Eckblad and Lehtinen 1991; Brewer 1992; Hornbach et al. 1993).

Although these studies contain valuable information, in many circumstances comparative data for long-term resource trends do not exist because of changes in methods or discontinued sampling. The LTRMP macroinvertebrate monitoring framework will provide a better understanding of the long-term changes in the UMRS natural resources.

Methods

Macroinvertebrate sampling was conducted in 1992–2002 in six study areas on the UMRS (Figure 1). The six LTRMP study areas represent the variety of aquatic areas within the UMRS. They range in size (calculated from geographic information system coverage; Lowenberg 1993) from 19,000 (Pool 8) to 107,000 ha (Open River Reach). Program study areas are referred to herein by the navigation pool designations according to the U.S. Army Corps of Engineers

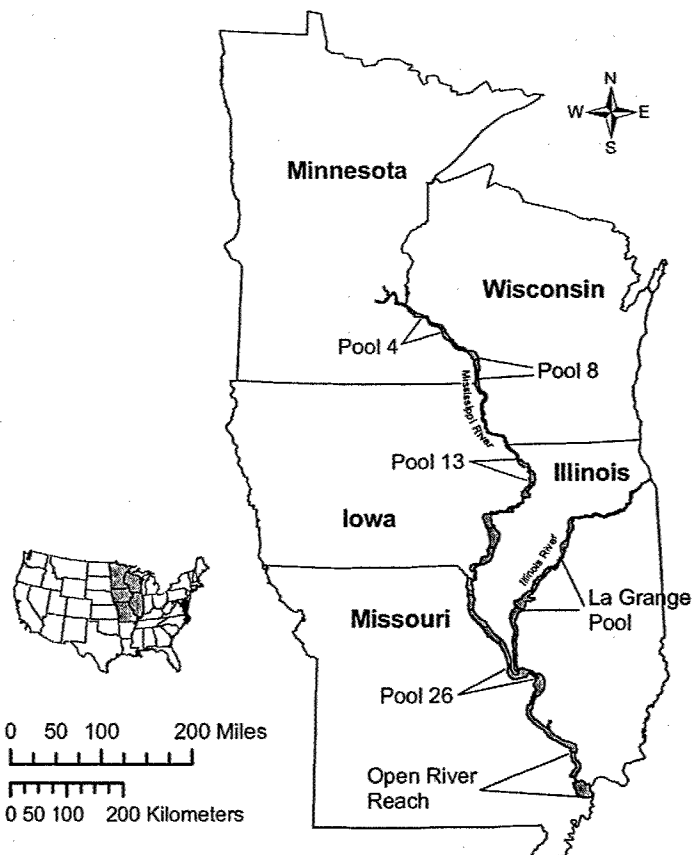


Figure 1. Study areas for macroinvertebrate sampling in the Long Term Resource Monitoring Program.

lock and dam system and include: Pools 4 (river miles 752 to 797), 8 (river miles 679 to 703), 13 (river miles 523 to 557), and 26 (river miles 202 to 242); the Open River Reach (river miles 29 to 80) of the Upper Mississippi River; and La Grange Pool (river miles 80 to 158) of the Illinois River (Figure 1).

The Open River Reach was dropped from the monitoring design in 2001 because of extremely low densities of burrowing mayflies (*Hexagenia* spp.) and fingernail clams and unfavorable habitat for these taxa (McDonald and Strickland 2001; Sauer 2003). Although Pool 26 and La Grange Pool also have low densities of the target organisms, these areas were kept in the monitoring design because they contain favorable habitat (i.e., soft substrates) for the target organisms. Monitoring should detect any changes (rebound) in the populations of the target organisms in these areas because of natural or anthropogenic changes in the system.

Initially, burrowing mayflies, fingernail clams, and the non-native Asiatic clam were selected for monitoring. Midges were added to the sampling design in 1993 and the non-native zebra mussel in 1995.

In addition to collecting abundance data on the target taxa, in 1998 we began recording the presence or absence of Amphipoda (scuds), Decapoda (freshwater shrimp and crayfish), Diptera (aquatic flies excluding Chironomids), Dreissenidae (zebra mussels), Gastropoda (snails), Odonata (dragonflies and damselflies), Oligochaeta (aquatic worms and leeches), Plecoptera (stoneflies), and Trichoptera (caddisflies). The first year of macroinvertebrate sampling was used to refine the sampling design, and changes have been documented in the LTRMP Procedures Manual (Thiel and Sauer 1999). Therefore, only 1993–2002 data will be used in statistical analysis of long-term trends.

The LTRMP staff developed a spatial database of aquatic areas (Owens and Ruhser 1996) on the basis of aerial photographs taken in 1989. This database was used to select sites for stratified random sampling and the quantification of sampling strata distribution and size. For LTRMP macroinvertebrate monitoring, random sample sites were selected from grids whose cells are 50 m². Sample sites also included some

historical (fixed) sites where benthic samples were previously collected by researchers (Appendix B).

Sampling was conducted annually at about 125 sites per study area in spring (April to mid-June) before the emergence of burrowing mayflies and substantial aquatic vegetation growth. Sample allocation was based on a stratified random design where strata were aquatic areas (Table 1). The LTRMP strata are groupings of aquatic area types at different levels within Wilcox's (1993) hierarchy:

- backwaters, contiguous (BWC)—non-channel areas lateral to the channel or within islands having apparent surface-water connection with channel habitats;
- main channel borders (MCB)—the area between the designated channel and the riverbank (not including revetments and channel-training structures);
- impounded areas (IMP)—the large, mostly open water areas in the downstream portion of the navigational pools;
- side channels (SC)—channels that carry less flow than the navigational channel; and
- tributary delta lake (TDL)—a natural lake formed by a river delta, which in Pool 4 is Lake Pepin, a natural lake formed by the Chippewa River delta.

In 1992, we used nine strata to distribute the macroinvertebrate monitoring sites. Some of these strata included aquatic vegetation, a seasonal attribute, as part of their definition. This classification scheme was reduced to five strata in 1993 when vegetation status was dropped from the strata designation.

Benthic samples were collected with a winch-mounted 0.052-m² standard Ponar grab sampler (Ponar Grab Dredge, Wildlife Supply Company, Saginaw, Michigan; Figure 2). Mayflies, fingernail clams, midges, Asiatic clams, and zebra mussels were picked and counted in the field (Figure 3). The wash frame sieve size was changed from a U.S. Standard Sieve no. 30 (595 µm), used in 1992, to a U.S. Standard Sieve no. 16 (1.18-mm) in 1993 to increase sorting efficiency for large-sized target organisms in the

Table 1. Annual numbers of random and fixed sample sites for macroinvertebrates, by study area and stratum from 1993 to 2002^a, and area (hectares) of strata available^b for macroinvertebrate sampling.

Study area	Backwater contiguous				Impounded				Side channel				Main channel border			
	Number of sites		Area (ha)		Number of sites		Area (ha)		Number of sites		Area (ha)		Number of sites		Area (ha)	
	random	Fixed	random	Fixed	random	Fixed	random	Fixed	random	Fixed	random	Fixed	random	Fixed	random	Fixed
Pool 4	57	3	2,301	1	44	1	9,368 ^c	—	10	—	722	—	10	—	563	—
Pool 8	31	3	1,762	11	49	11	3,505	—	19	2	1,377	—	10	—	632	—
Pool 13	43	2	2,779	1	46	1	3,672	—	14	4	985	—	15	—	1,145	—
Pool 26	40	—	412	—	27	—	190	—	34	3	1,496	—	17	4	3,312	—
Open River Reach	—	—	—	—	—	—	—	—	64	16	437	—	43	2	3,384	—
La Grange Pool	24	18	1,136	—	—	—	—	—	35	7	179	—	40	1	2,444	—

^aSample size varies over years because of sampling difficulties (Sauer 2003).

^bNot all of the aquatic area in the study area is accessible for macroinvertebrate sampling.

^cImpounded area for Pool 4 is Lake Pepin, a Tributary Delta Lake.

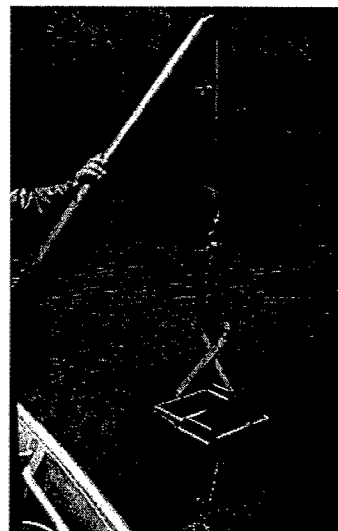


Figure 2. Winch-mounted standard Ponar grab sampler.



Figure 3. Field crew from the Long Term Resource Monitoring Program sorting macroinvertebrates from a Ponar sample.

field. Thus, inferences on macroinvertebrate numbers from these data (1993–present) are restricted to larger individuals (see Dukerscheim et al. 1996 for size measurements). In certain years, after the picking process was complete, leaving only detritus and organisms other than the target organisms, it was determined by random draw whether the sample would be brought back to the laboratory for quality assurance (Norris and Georges 1992). A total of 10% of the sites sampled within each stratum each year were brought back to the laboratory to evaluate field-picking efficiency. Macroinvertebrates found in the laboratory sorting process were not included in analyses.

At each site, substrate composition was determined by subjective characterization. Six categories of substrate composition were used:

hard clay, silt clay, silt clay with sand, sand with silt clay, sand, and gravel rock. The percentage of surface area coverage of submersed and floating-leaf aquatic vegetation was estimated in the column of water through which the Ponar dredge fell. The type and abundance of vegetation and open water in a 15-m radius from the boat were qualitatively characterized. Water depth also was measured at each site.

The number of each target taxa collected was recorded from individual Ponar samples. Whenever target taxa were not caught in a sample, the catch for those taxa in that sample was recorded as zero. Macroinvertebrate sampling procedures are described in detail in the LTRMP Procedures Manual (Thiel and Sauer 1999).

Frequency distributions varied among years; in 1992 low densities (<20 organisms per sample) were common, and higher densities (≥ 20) were present in about 6% of the samples (Figure 4). In 1992, stratified random sampling sites were distributed equally among the strata. After analysis of the 1992 data—where 57% of the samples did not contain any target

organisms—we decided to sample more suitable habitat of the target organisms (i.e., soft-sediment substrate; Table 1) with more frequency. The U.S. Environmental Protection Agency (2003) monitoring program states that more sampling effort in one area will not bias the data.

Analyses of densities (DS) for temporal trends among mayflies, fingernail clams, and midges were based on estimates of mean densities (\overline{DS}) obtained by pooling data over all strata within a study area.

The presence of differences between LTRMP study areas and trends was tested. All models were fitted using SAS[®] mixed modeling procedure (PROC MIXED[®]; SAS 2000). Imposing some simplifying assumptions, we tested for simple linear trends (straight-line increases or decreases) over the 10-year period and also comparisons of these trends among the LTRMP study areas. It was not feasible to perform more detailed time series and trend analyses because the data series were too short (i.e., in essence $N = 10$ per study area). Historical (fixed) sites were removed for this analysis. Data from the Open River Reach study area were

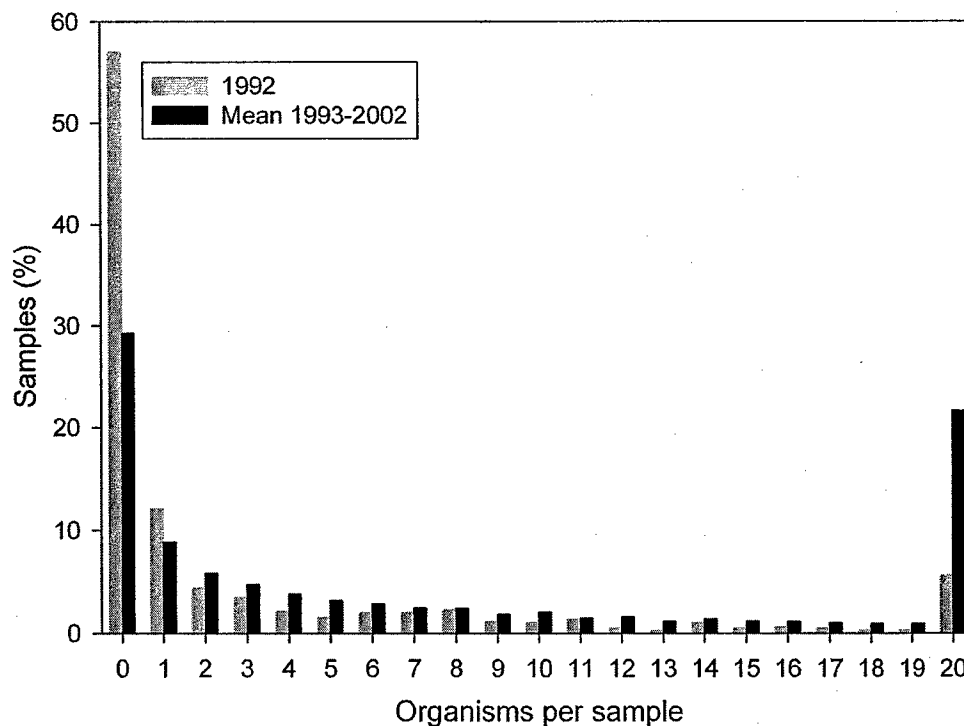


Figure 4. Frequency of presence of number of target macroinvertebrates per sample from the Long Term Resource Monitoring Program. After 1992, sampling was modified by shifting more effort to soft substrates, which are more suitable for the target taxa.

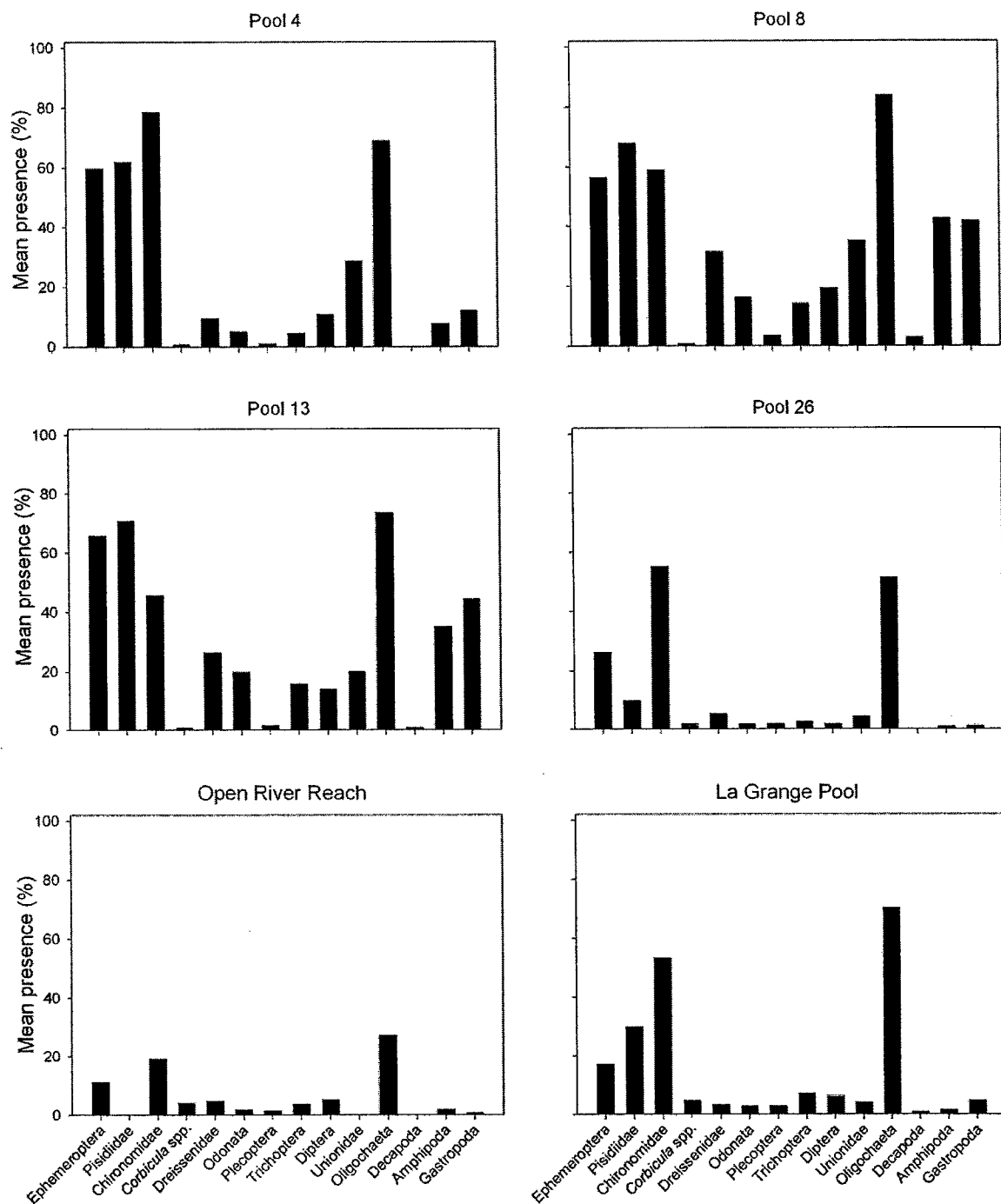


Figure 5. Mean percentage of presence of taxa sampled by the Long Term Resource Monitoring Program. All years combined (1993–2002). Taxa include Ephemeroptera (mayflies), Pisidiidae (fingernail clams), Chironomidae (midges), *Corbicula* spp. (Asiatic clams), Dreissenidae (zebra mussels), Odonata (dragonflies and damselflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Diptera (aquatic flies excluding Chironomids), Unionidae (freshwater mussels), Oligochaeta (aquatic worms and leeches), Decapoda (freshwater shrimp and crayfish), Amphipoda (scuds), and Gastropoda (snails).

(Table 4; Figure 7). The lowest \overline{DS} of mayflies throughout the 10 years of sampling were from Pool 26, the Open River Reach, and La Grange Pool. Pool 13 had the most consistent densities

over the years until 2001 when \overline{DS} reached a low of 77 m⁻²; however, numbers rebounded in 2002. No estimated mean densities of mayflies were calculated for Pool 26 in 1995 because

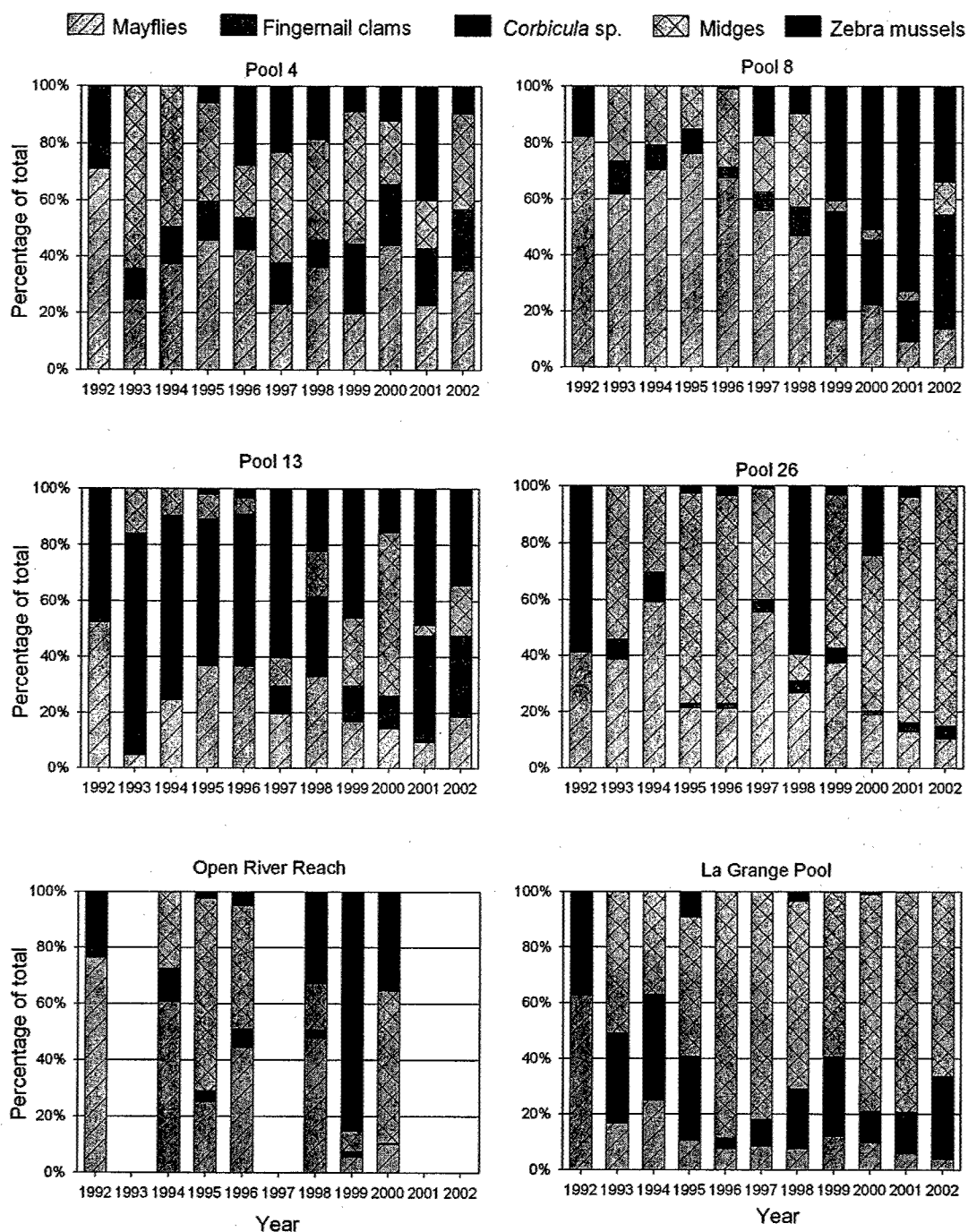


Figure 6. Percent composition of mayflies (Ephemeroptera), fingernail clams (Pisidiidae), Asiatic clams (*Corbicula* spp.), midges (Chironomidae), and zebra mussels (*Dreissena polymorpha*) in samples by study area. Open River Reach not sampled in 1993 or 1997 because of high water. Sampling discontinued in the Open River Reach in 2001.

field crews were not able to sample certain sites because of high water. Pool 8 had the largest range in \overline{DS} (223.6 m²).

Although mean densities of mayflies varied over the years among strata, the IMP, TDL, and

BWC strata supported the highest mean number of mayflies in Pools 4, 13, and 26 (Figure 8). Highest mean mayfly densities in Pool 8 were present in side channel and impounded strata. Side channel areas had the highest mayfly

not included for analysis, but were included in general description of the data. Data used in this report can be downloaded from http://www.umesc.usgs.gov/data_library/macrobenthos/invert1_query.html.

Differences between field stations and the presence of temporal trends were investigated using log-transformed poolwide means. Means were estimated from data deriving from our stratified random survey design using standard design-based assumptions (Cochrane 1977). Because of the short time series, linear trends (on the log scale) were assumed (note that linear trends on the log scale correspond to exponential trends on the untransformed scale). We made an assumption of independence across years; an assumption that has generally appeared reasonable for the LTRMP macroinvertebrate data (Brian Gray, U.S. Geological Survey, La Crosse, Wisconsin, personal communication) and corresponds to the observation that life cycles of the primary taxa groups are 1 year or less.

Variance components were estimated using a method-of-moments approach (Lenter and Bishop 1986) on transformed data. To avoid estimating across different strata, annual and error variances were estimated from backwater contiguous sample sites only.

Results: Stratified Random Sampling

More than 6,090 Ponar collections (stratified random sampling sites) were made from the six study areas in spring 1993 to 2002. Water depths at sampling sites ranged from 0.10 to 18.5 m. Visual classification of sediments indicated that sample sites in Pools 4, 8, 13, and 26 and La Grange Pool were dominated by silt clay. In the Open River Reach, main channel border and side channel strata were dominated by sand.

Mayflies and fingernail clams were most prevalent in the upper three LTRMP pools (Pools 4, 8, and 13; Figure 5). Midge and aquatic worms and leeches (Oligochaete) were present in relatively high frequency of samples in all study areas except the Open River Reach. Not all taxa found inhabit soft substrates so they are not expected in great numbers in a Ponar sample.

Percent composition of target organisms varied among years within study areas (Figure 6). Between 1993 and 1998, Pool 8 consistently had higher percentages of mayflies than any of the other four target organisms. However, from 1999 to 2001, zebra mussels became more prevalent than the other taxa. Pool 13 had high percentages of fingernail clams in 1993–1996, whereas zebra mussels dominated in 1997, 1999, 2001, and 2002 when compared with other target organisms. Pool 26 had high percentages of midges for most of the years except 1998 when zebra mussels were most prevalent. Midges dominated samples in La Grange Pool from 1993 to 2002.

The variance component estimates indicate that, on average, the majority of the variance seen among mayfly, fingernail clam, and midge annual means is derived from real changes in those means (Table 2). A minority of the year-to-year variance was attributed to sampling or error variance. The error variance refers to unexplained variation. The Open River Reach was not included in this analysis.

Target Macroinvertebrates

Variation associated with log-transformed means of mayfly, fingernail clam, and midge abundance data appeared primarily associated with study area only (Table 3). This reflects the large differences in abundances seen among the study areas (Table 4). Monotonic trends between 1993 and 2002 in mean densities of mayflies and midges were not visually apparent or statistically significant. The marginally significant trend-study area interaction term for fingernail clams was associated with a substantial increase in abundance in Pool 8 only.

Asiatic clams and zebra mussels were not included in the trend analyses because of low numbers (Table 4).

Mayflies

Estimated poolwide mean densities (\bar{D}_S) of mayflies ranged from a low of 3 m⁻² in La Grange Pool in 2001 and in the Open River Reach in 1999 to a high of 262 m⁻² in Pool 8 in 2000

Table 2. Percentage of total annual variance associated with the true annual variance (real change in the means) in backwater, contiguous aquatic areas for mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and midges (Chironomidae) by study area.

Study area	Mayflies (%)	Fingernail clams (%)	Midges (%)
Pool 4	73	67	89
Pool 8	49	86	86
Pool 13	84	67	91
Pool 26	93	64	79
La Grange Pool	71	50	77

Table 3. Statistical significance of year, study area, and interaction terms for mean abundances of mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and midges (Chironomidae).

	Degrees of freedom		F	Pr > F
	Numerator	Denominator	Value	
Mayflies ^a				
Year	1	31.8	0.04	0.8471
Study area	4	16.5	75.33	<0.0001
Interaction	4	16.5	1.65	0.2102
Fingernail clams ^a				
Year	1	26.4	1.08	0.3083
Study Area	4	15.4	37.60	<0.0001
Interaction	4	15.4	3.23	0.0417
Midges ^a				
Year	1	25.5	1.04	0.3170
Study area	4	16.9	11.16	0.0001
Interaction	4	16.9	1.15	0.3675

^aOpen River Reach removed for analysis.

densities in La Grange Pool in 1993–2002. Overall, MCB areas supported the lowest densities of mayflies in all study areas.

The silt clay substrate tended to support the highest mean numbers of mayflies in all study areas (Figure 9). The large-particle substrates (i.e., sand with silt, sand, and gravel rock) had the lowest numbers of mayflies.

Fingernail Clams

Estimated poolwide densities of fingernail clams ranged from zero in Pool 26 (1996, 2000, and 2002) and Open River Reach (1995–1996, 1998–2000) to more than 2,500 m⁻² in Pool 13 in 1993 (Table 4; Figure 10). The density seen in Pool 13 in 1993 was 35 times that found in other study areas for the same year. In 1993–1998, relatively low numbers of fingernail clams in

Pools 4 and 8 were reported; however, densities increased in 1999. Pool 13 had the largest range in mean density (2,489.7 m⁻²) for the study period.

Over all years, in Pool 8, IMP and SC strata supported the highest densities of fingernail clams, whereas in Pools 4, 13, and 26 IMP strata, including the naturally impounded Lake Pepin, supported the highest densities of fingernail clams (Figure 11). Side channel areas had the highest fingernail clam densities in La Grange Pool, which has no impounded stratum. The IMP stratum seems to have more favorable habitat for fingernail clams.

The silt clay and silt clay with sand substrates tended to support the highest number of fingernail clams (Figure 12). The large-particle substrates (sand with silt, sand, and gravel rock) supported the lowest densities of fingernail clams.

Midges

Poolwide estimates of midges ranged from a high of 570 m⁻² in Pool 13 in 2000 to a low of 4 m⁻² in the Open River Reach in 1998 (Table 4; Figure 13). Although no significant linear trends were detected, Pools 4, 8, and 13 experienced apparent declines in midge densities from 1993 to 1996; but then began an increase in densities in 1997. Pools 4 and 13 and La Grange Pool contained the highest \overline{DS} of midges (Table 4). The lowest \overline{DS} of midges was from the Open River Reach. Pool 13 had the largest range in \overline{DS} (552.7 m⁻²) over the study period compared with other study areas.

Midge densities varied widely among strata over years and study areas. The BWC strata had the highest densities of midges in Pools 8, 13, and 26 and La Grange Pool. In Pool 4, midge densities were highest in Lake Pepin (Figure 14).

The small-particle substrates (silt clay and silt clay with sand) tended to support the highest mean number of midges over all years in all study areas (Figure 15).

Table 4. Estimated mean densities of mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and midges (Chironomidae), Asiatic clams (*Corbicula* spp.), and zebra mussels (*Dreissena polymorpha*) by year and study area, weighted by areas of strata. *N* = sample size, SE = standard error.

Study area and year ^a (<i>N</i>)	Mayflies (m ⁻²) (±1 SE)	Fingernail clams (m ⁻²) (±1 SE)	Midges (m ⁻²) ^b (±1 SE)	Asiatic clams (m ⁻²) (±1 SE)	Zebra mussels ^c (m ⁻²) (±1 SE)
Pool 4					
1992 (122)	59 (18)	47 (19)	— ^d	0 (0)	—
1993 (121)	123 (35)	71 (10)	306 (38)	0 (0)	—
1994 (125)	196 (49)	84 (12)	182 (32)	0 (0)	—
1995 (121)	171 (34)	59 (13)	78 (13)	0 (0)	26 (26)
1996 (121)	132 (34)	39 (7)	38 (12)	0 (0)	116 (113)
1997 (120)	69 (18)	76 (9)	152 (35)	0 (0)	31 (27)
1998 (121)	209 (44)	73 (10)	253 (40)	0 (0)	107 (98)
1999 (120)	69 (18)	138 (21)	199 (33)	0 (0)	37 (33)
2000 (120)	223 (39)	118 (14)	65 (15)	0 (0)	31 (29)
2001 (119)	104 (19)	103 (14)	71 (13)	0 (0)	232 (218)
2002 (121)	93 (31)	79 (10)	68 (16)	0 (0)	8 (6)
Pool 8					
1992 (109)	51 (25)	15 (11)	—	0 (0)	—
1993 (109)	117 (40)	22 (11)	50 (9)	0 (0)	—
1994 (112)	91 (31)	11 (5)	26 (16)	0 (0)	—
1995 (109)	56 (14)	6 (3)	11 (4)	0 (0)	0 (0)
1996 (109)	38 (11)	2 (1)	15 (4)	0 (0)	1 (0)
1997 (112)	71 (16)	9 (4)	26 (6)	0 (0)	25 (11)
1998 (109)	120 (36)	26 (8)	82 (18)	0 (0)	26 (17)
1999 (107)	212 (57)	507 (155)	45 (15)	0 (0)	825 (581)
2000 (107)	262 (70)	270 (55)	38 (12)	0 (0)	609 (349)
2001 (108)	104 (30)	170 (39)	38 (10)	0 (0)	882 (563)
2002 (109)	75 (25)	236 (39)	62 (17)	0 (0)	196 (113)
Pool 13					
1992 (118)	120 (31)	84 (28)	—	0 (0)	—
1993 (119)	150 (38)	2,571 (489)	496 (93)	0 (0)	—
1994 (125)	189 (35)	606 (160)	73 (34)	0 (0)	—
1995 (118)	182 (52)	265 (83)	38 (9)	0 (0)	10 (7)
1996 (118)	148 (38)	231 (58)	21 (7)	0 (0)	14 (8)
1997 (118)	165 (43)	87 (23)	78 (36)	0 (0)	559 (446)
1998 (118)	167 (45)	150 (33)	79 (27)	0 (0)	120 (93)
1999 (118)	186 (46)	145 (33)	232 (74)	0 (0)	527 (320)
2000 (118)	158 (51)	126 (37)	570 (87)	0 (0)	172 (131)
2001 (117)	77 (19)	332 (121)	28 (14)	0 (0)	427 (168)
2002 (118)	220 (54)	365 (86)	190 (47)	0 (0)	448 (201)
Pool 26					
1992 (117)	21 (10)	15 (9)	—	2 (1)	—
1993 (66)	7 (2)	1 (1)	11 (2)	0 (0)	—
1994 (124)	22 (7)	5 (3)	14 (8)	1 (1)	—
1995 (67) ^e	—	—	—	—	—
1996 (112)	13 (10)	0 (0)	18 (9)	0 (0)	0 (0)
1997 (87)	16 (8)	1 (1)	13 (6)	0 (0)	1 (1)
1998 (72)	25 (16)	4 (4)	5 (2)	4 (3)	30 (25)
1999 (117)	28 (15)	1 (1)	9 (4)	1 (1)	2 (2)
2000 (118)	27 (11)	0 (0)	27 (8)	2 (2)	109 (105)
2001 (115)	7 (3)	2 (1)	30 (8)	0 (0)	7 (6)
2002 (104)	44 (22)	0 (0)	53 (14)	0 (0)	0 (0)

Table 4. Continued

Study area and year ^a (N)	Mayflies (m ²) (±1 SE)	Fingernail clams (m ²) (±1 SE)	Midges (m ²) ^b (±1 SE)	Asiatic clams (m ²) (±1 SE)	Zebra mussels ^c (m ²) (±1 SE)
Open River ^{d,e}					
1992 (92)	22 (12)	5 (3)	—	1 (1)	—
1993	—	—	—	—	—
1994 (84)	19 (9)	1 (1)	8 (4)	2 (1)	—
1995 (113)	12 (6)	0 (0)	14 (5)	2 (1)	2 (2)
1996 (107)	11 (6)	0 (0)	5 (2)	1 (1)	0 (0)
1997	—	—	—	—	—
1998 (108)	12 (9)	0 (0)	4 (2)	1 (1)	20 (17)
1999 (108)	3 (2)	0 (0)	6 (3)	1 (1)	100 (74)
2000 (97)	9 (5)	0 (0)	22 (7)	0 (0)	71 (64)
La Grange Pool					
1992 (102)	13 (6)	4 (2)	—	0 (0)	—
1993 (98)	10 (4)	18 (10)	47 (13)	0 (0)	—
1994 (124)	24 (8)	53 (13)	57 (10)	12 (3)	—
1995 (97)	6 (4)	17 (9)	29 (11)	2 (1)	11 (11)
1996 (98)	4 (1)	5 (3)	150 (50)	1 (1)	0 (0)
1997 (99)	8 (3)	9 (5)	101 (33)	0 (0)	0 (0)
1998 (99)	9 (6)	21 (12)	91 (25)	1 (1)	3 (1)
1999 (98)	9 (5)	13 (5)	46 (16)	0 (0)	0 (0)
2000 (99)	7 (5)	10 (8)	67 (22)	0 (0)	1 (1)
2001 (98)	3 (1)	9 (4)	51 (13)	0 (0)	0 (0)
2002 (99)	4 (2)	33 (14)	98 (20)	0 (0)	0 (0)

^aIn 1992, a mesh size of 595 µm was used. In all other years, a mesh size of 1.18 mm was used. ^bSampling began in 1993. ^cSampling began in 1995. ^dA dash (—) indicates no data. ^eSampling not completed in 1995 because of high water. ^fSampling not done in 1993 or 1997 because of high water. ^gSampling discontinued in 2001.

Asiatic Clams and Zebra Mussels

Because of the low number of Asiatic clams and zebra mussels (Table 4), no statistical analyses were undertaken; however descriptive statistics follow. Low numbers of Asiatic clams were found in all study areas. Fewer than 15% of the samples contained Asiatic clams and zebra mussels. No study areas had estimated densities of more than 115 m⁻² Asiatic clams (six individuals in a sample). Zebra mussel densities were extremely low in La Grange Pool in all years of monitoring (Figure 16). Densities of zebra mussels are most likely underrepresented because we sampled mainly soft substrates rather than the hard substrates that zebra mussels prefer.

Zebra mussel densities were highest in MCB and IMP strata. The highest mean densities of zebra mussels in all study areas were found in the gravel rock substrate, which is preferred by zebra mussels for attachment by their byssal threads.

Results: Historical (Fixed) Sites

More than 730 samples were collected from historical sites (fixed sites; Appendix B) in the six study areas from 1993 to 2002. Only mayflies and fingernail clam densities were examined since they were the most consistent taxa reported historically.

Pool 4

In Pool 4, four historical sites sampled by North Star Research Institute (1973) were resampled by the LTRMP from 1993 to 2002 (Appendix B). The highest number of mayflies and fingernail clams reported by North Star Research Institute (1973) were at historical sites 502 and 503, where they reported concentrations of mayflies at 105.8 m⁻² and of fingernail clams at 86.5 m⁻² (Appendix C). In LTRMP data from 1993 to 2002, the highest densities of mayflies

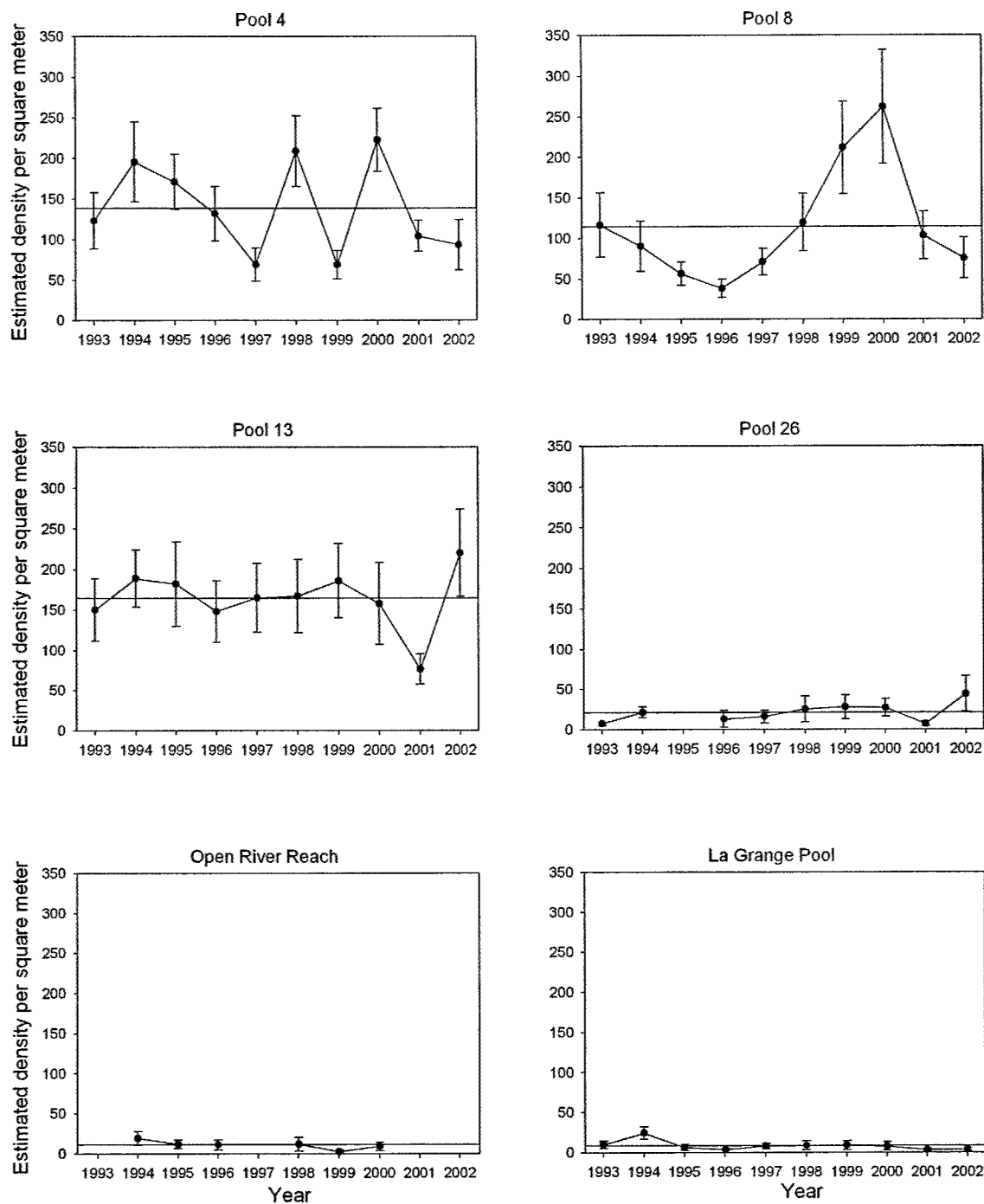


Figure 7. Estimated density of mayflies (Ephemeroptera; number per square meter, ± 1 standard error) by study area, weighted by area of strata. Horizontal line indicates grand mean.

were 576.9 m^{-2} (site 504; BWC) and of fingernail clams were 403.8 m^{-2} (site 501; TDL). Over the years, abundance of mayflies was highest at sample site 504—BWC strata. Fingernail clam densities were highest in the TDL stratum. Sites 501 and 504 were the most productive sites over all years of the present study.

Pool 8

For LTRMP macroinvertebrate sampling, 16 sites were resampled (Appendix B). Two researchers sampled historical sites in Pool 8 (Elstad 1977; Brewer 1992). The highest number of mayflies and fingernail clams reported by

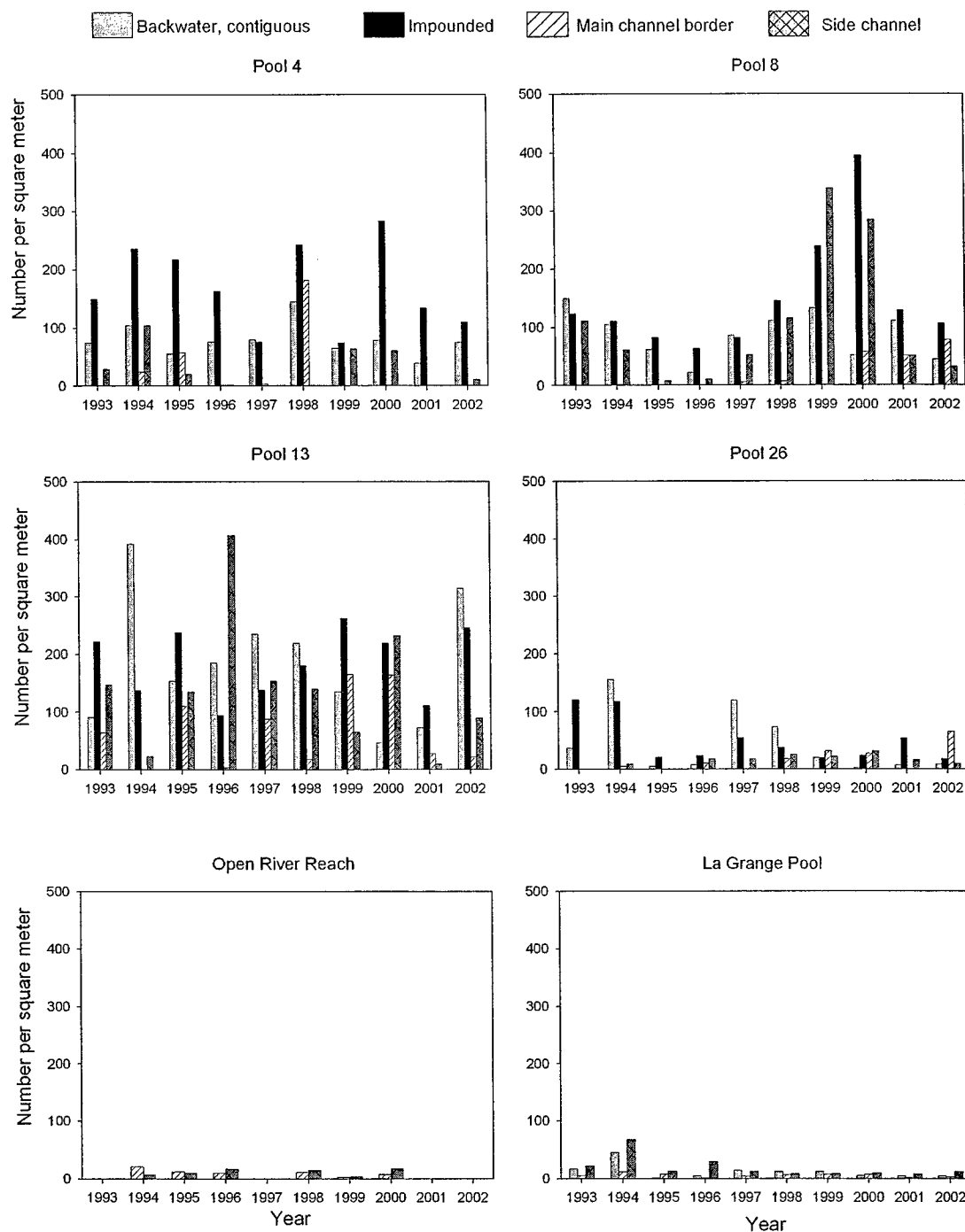


Figure 8. Mean density of mayflies (Ephemeroptera; number per square meter) by study reach and aquatic strata. Impounded area for Pool 4 is Lake Pepin, a Tributary Delta Lake.

Elstad (1977) at sample sites in Pool 8 were 1,353.5 (site 504) and 5,184.9 m^{-2} (site 503), respectively (Appendix C). Brewer (1992) noted significant declines in total macroinvertebrate abundance in open water habitats and no significant changes in marsh, channel, and

dredge areas when compared to Elstad's (1977) findings. The highest density of mayflies found by Brewer (1992) was 241.3 m^{-2} , and the highest density of fingernail clams was 243.5 m^{-2} . In LTRMP data from 1993 to 2002, the highest densities of mayflies and fingernail clams were

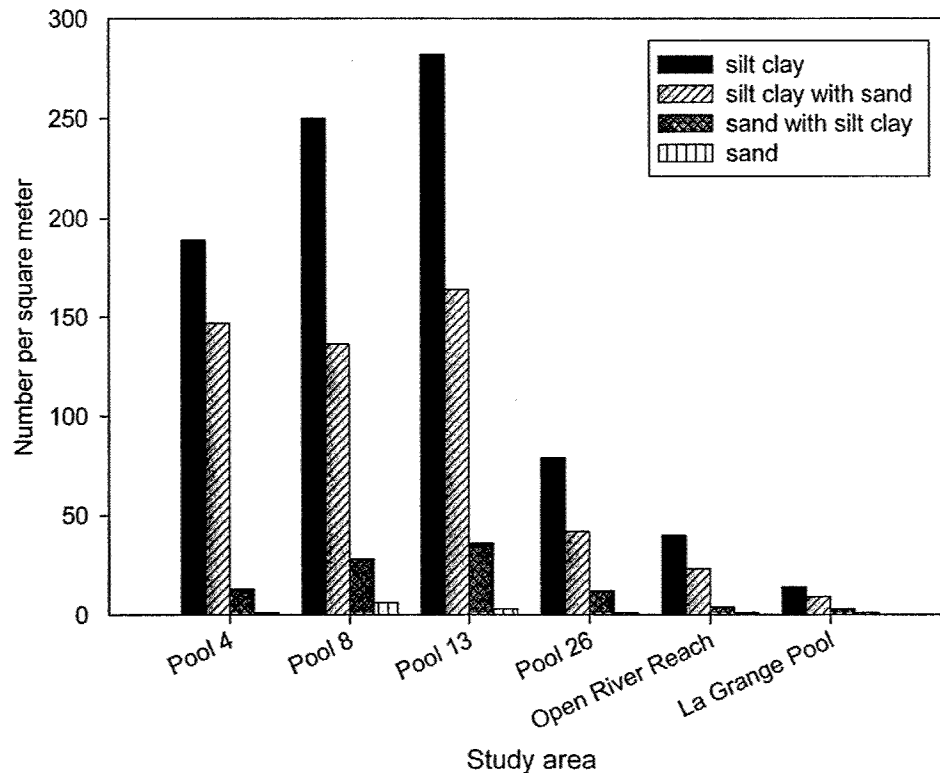


Figure 9. Estimated mean density of mayflies (Ephemeroptera; number per square meter) by predominant substrate type, weighted by areas of strata. Because of small sample sizes, substrates defined as clay were combined with the silt clay category and gravel rock with the sand category. All years combined (1993–2002).

at site 515; IMP strata (3,500.0 and 12,134.6 m^{-2} , respectively; Appendix C). Over the years, mayfly densities were highest at sample sites 502, 504–506, 510, and 514—BWC and IMP areas. Fingernail clam distribution was highest in the IMP strata.

Pool 13

Seven sites sampled by Hubert et al. (1983) in February and March 1983 were chosen to be resampled for the LTRMP (Appendix B). The highest number reported by Hubert et al. (1983) at historical sites for mayflies was 1,017.4 m^{-2} (site 502; SC) and for fingernail clams was 1,544.6 m^{-2} (site 507; IMP; Appendix C). Between 1993 and 2002, the highest densities of mayflies and fingernail clams were 1,615.4 and 4,096.2 m^{-2} (site 503; SC), respectively. For these same years, mayfly densities were consistently high at sample sites 502–506 (SC strata). Fingernail clam densities were greatest at sites 503 and 504.

In 1983, Hubert et al. observed that lake habitats ($N = 18$) supported a mean of 66 m^{-2} *Hexagenia* mayflies and 295 m^{-2} *Sphaerium* fingernail clams. In three of the lake sites resampled for the LTRMP (sites 505, BWC; 506, BWC; and 507, IMP), mean densities of mayflies were from 0.0 to 1,557.7 m^{-2} and mean densities of fingernail clams were from 0 to 1,134.6 m^{-2} . Site 507 has never reached the densities found in Hubert's (1983) study (Appendix C).

Pool 26

A total of seven historical sites in Pool 26 were chosen to be resampled for the LTRMP (Appendix B). The highest number of mayflies and fingernail clams observed by Colbert et al. (1975) in July 1974 at historical sites in Pool 26 (Appendix C) was 172.0 (site 503; SC) and 25.0 m^{-2} (site 501; MCB), respectively. Between 1993 and 2002, the highest densities of mayflies and fingernail clams were 1,038.5 and 57.7 m^{-2} (site 507; SC), respectively. In fact, site 507

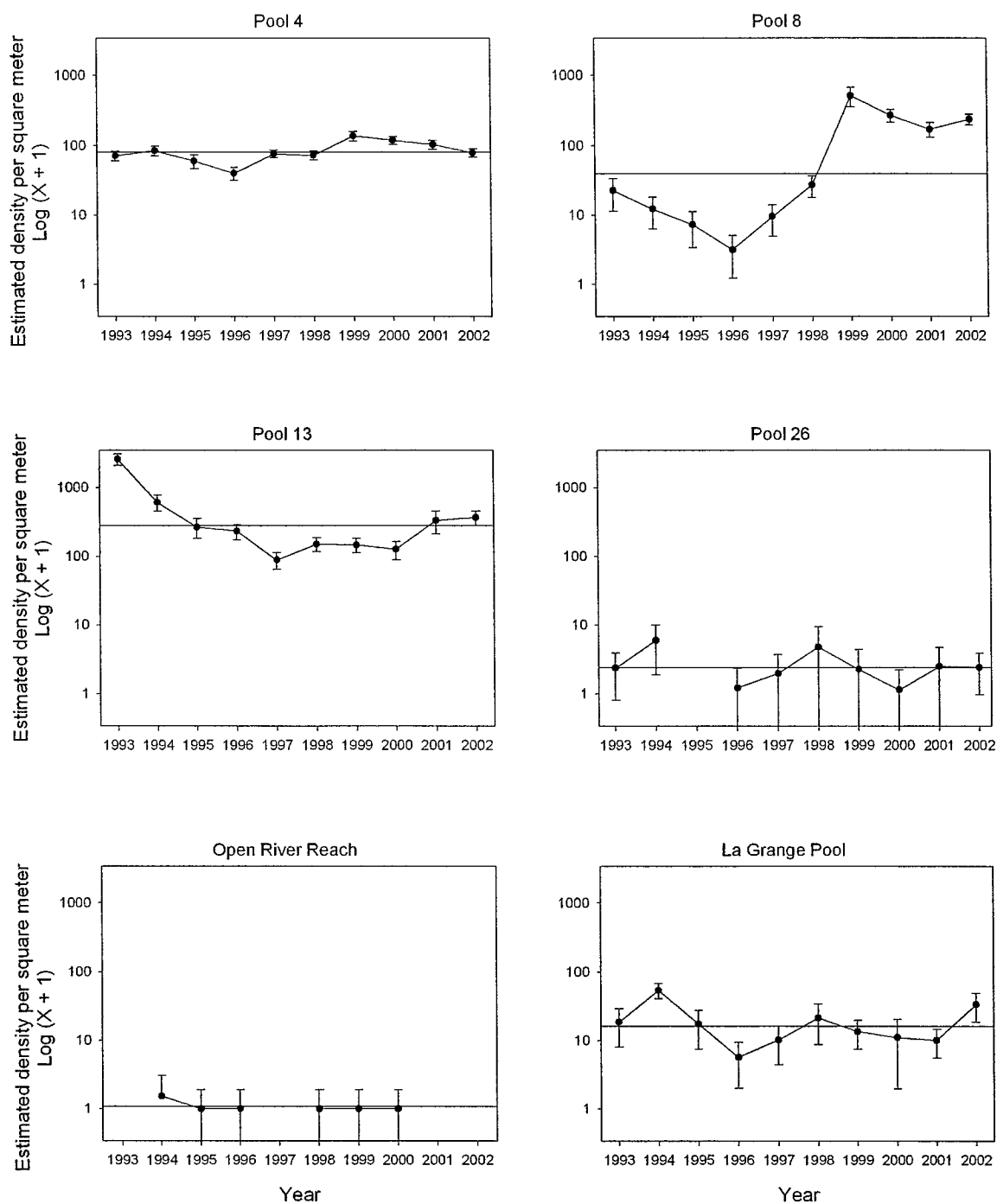


Figure 10. Estimated density of fingernail clams (Pisidiidae; number per square meter, ± 1 standard error) by study area, weighted by area of strata. Horizontal line indicates grand mean.

was the only site in which fingernail clams were present for all 10 years of monitoring. The highest densities of mayflies were measured at sample site 503, a SC strata. Seagle et al. (1982) reported a *Hexagenia* density as high as 454 m⁻² ($N = 9$; 5 replicates at each site).

Open River Reach

Eighteen sites sampled by Emge et al. (1974) in summers 1972 and 1973 were chosen to be resampled for the LTRMP (Appendix B). The highest number of mayflies reported by Emge

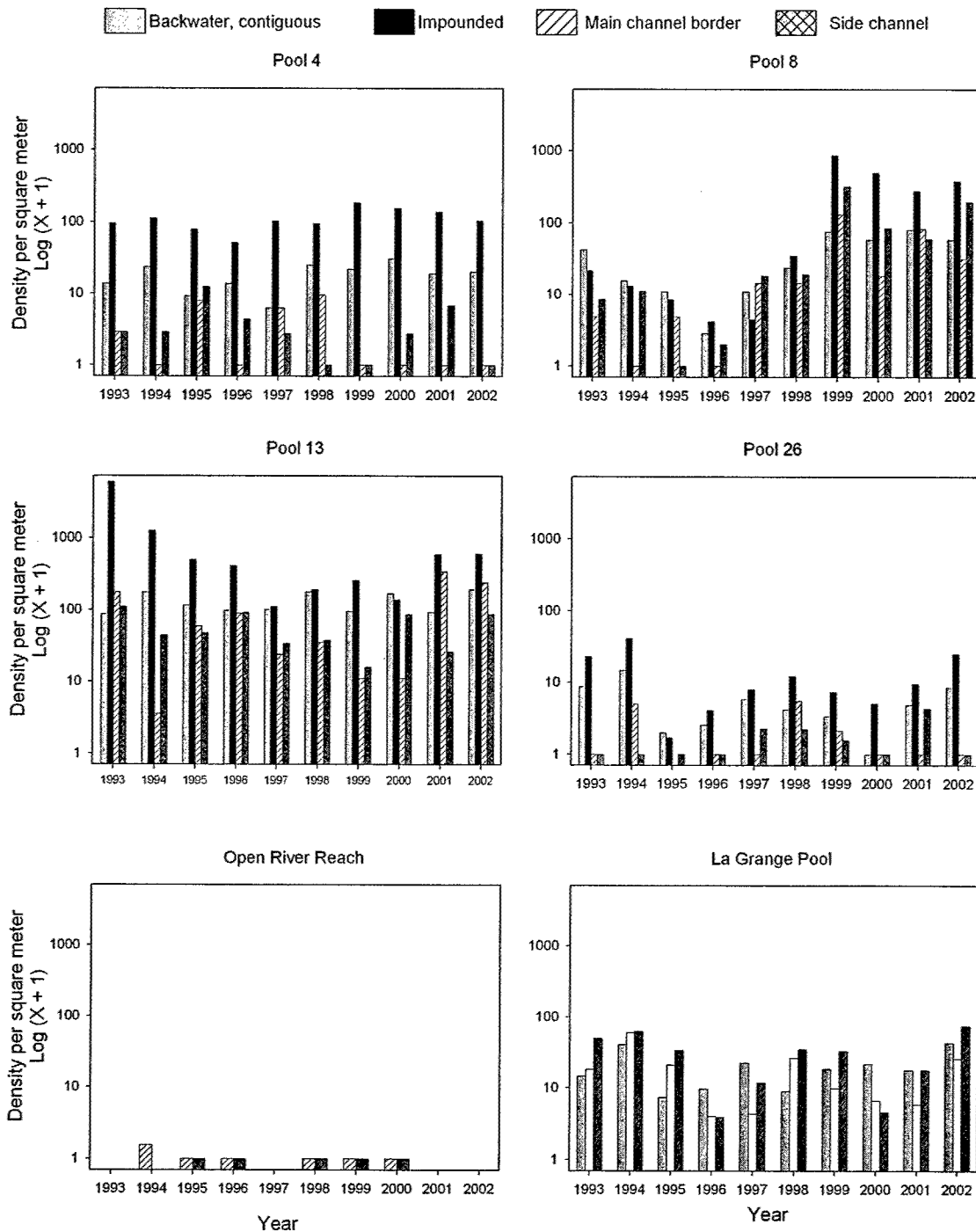


Figure 11. Mean density of fingernail clams (*Pisidiidae*; number per square meter) by study reach and aquatic strata. Impounded area for Pool 4 is Lake Pepin, a Tributary Delta Lake..

et al. (1974) at sample sites in the Open River Reach (Appendix C) was 675.0 m^{-2} (site 518; MCB). Between 1993 and 2000, the highest densities of mayflies were 384.6 m^{-2} (site 515; SC). Over the years, the highest density

of mayflies was at sample site 515; SC area. Fingernail clams were not found at any of the sites. This was consistent with Emge et al. (1974) findings.

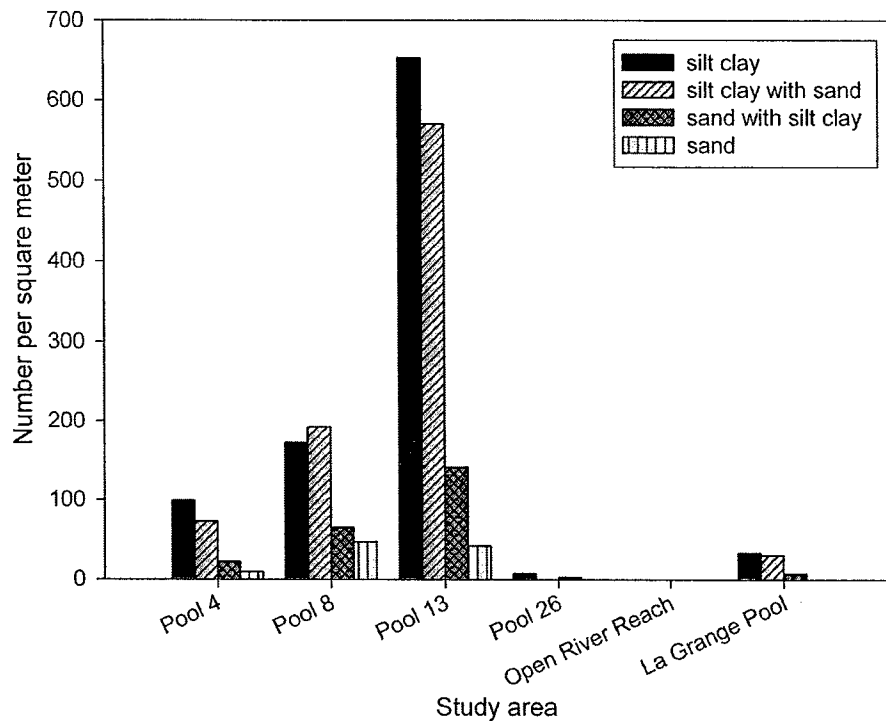


Figure 12. Estimated mean density of fingernail clams (*Pisidiidae*; number per square meter) by predominant substrate type, weighted by areas of strata. Because of small sample sizes, substrates defined as clay were combined with the silt clay category and gravel rock with the sand category. All years combined (1993–2002).

La Grange Pool

Twenty-six sites sampled by Paloumpis and Starrett (1960) in 1952–1954 and Anderson (1977) in September 1975 were chosen to be resampled for the LTRMP (Appendix B). The highest concentration reported by Anderson (1977) for mayflies was 34.4 m⁻² (site 523; SC) and for fingernail clams was 34.4 m⁻² (site 524; SC; Appendix C). In Appendix C, the LTRMP sites 501–509 were combined to represent Lake Matanzas and sites 510–522 were combined to represent Quiver Lake. The highest densities of mayflies were in Quiver Lake. Fingernail clam distribution was also highest in the Quiver Lake area with a mean maximum of 17,201.9 m⁻² in 1952, reported by Paloumpis and Starrett (1960). Fingernail clams were virtually nonexistent in Lake Matanzas from 1993 to 2002 (Appendix C).

Discussion

A number of studies have shown the target taxa, especially mayflies, fingernail clams,

and midges, to be ecologically important as fish and waterfowl food, biological indicators, and converters of phytoplankton and bacteria to higher energy pathways (Hoopes 1960; Fremling 1964, 1989; Jude 1968; Ranthum 1969; Thompson 1973; Anderson et al. 1978; Sandusky and Sparks 1979; Reice and Wohlenberg 1992; Rosenberg and Resh 1993; Winter et al. 1996; Diggins and Stewart 1998; Schloesser and Nalepa 2001; Tyson and Knight 2001). For these reasons, there is much interest in tracking the abundance of these taxa.

In the 1950s, much concern arose when mayfly densities crashed in the Upper Mississippi River System and Lake Erie (Fremling 1964; Mills et al. 1966; Kreiger et al. 1996). The last large emergence of mayflies near Havana, Illinois, was in 1949 (Mills et al. 1966). In 1976 in Lake Pepin, Pool 4, Trapp (1979) collected only 28 mayfly (*Hexagenia*) nymphs from 50 stations. By 1986, follow up investigations of Trapp's work yielded 369 mayfly nymphs (Fremling and Johnson 1990). Fremling (1989) detected the rebound of mayflies in Pool 2 and Lake

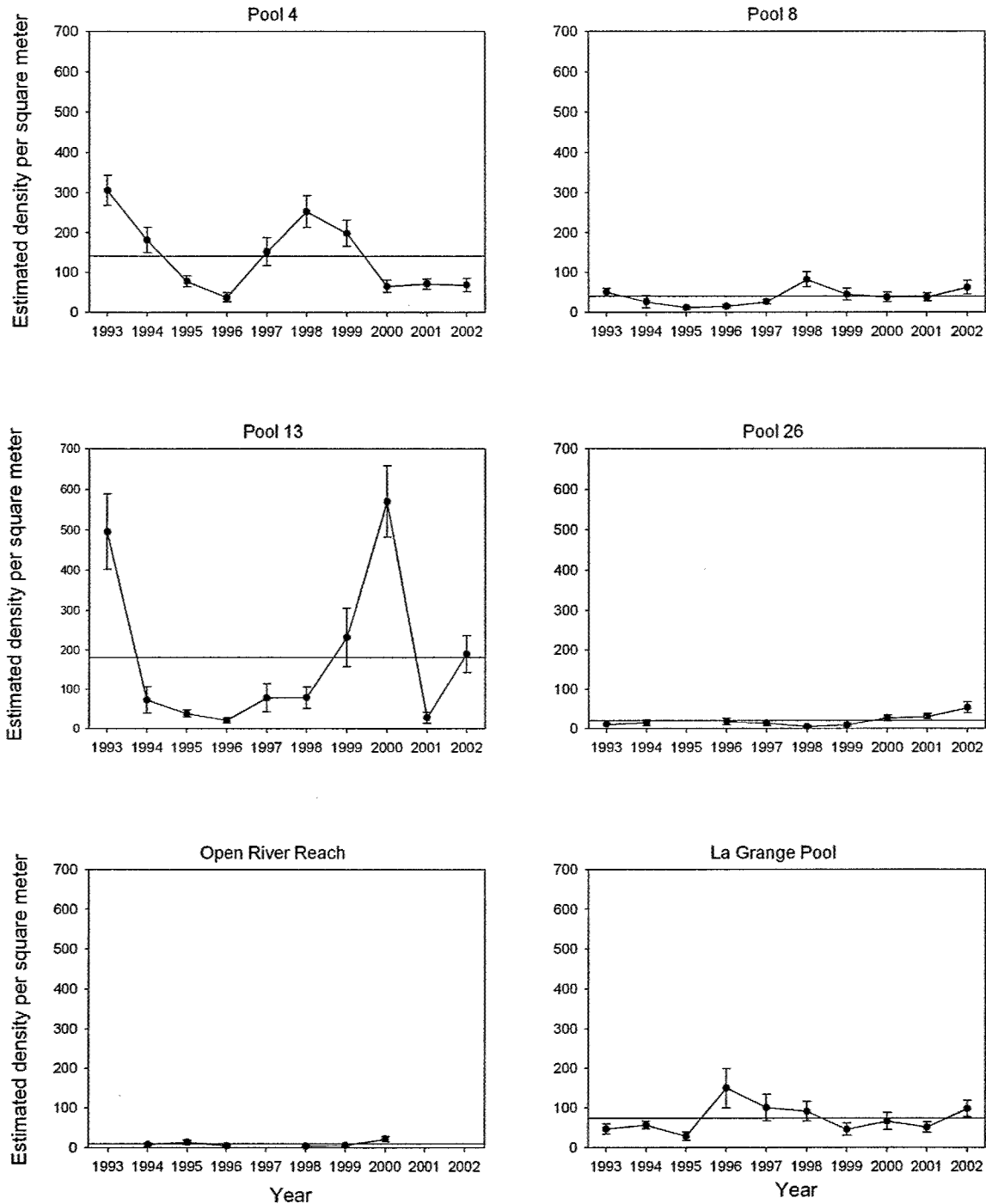


Figure 13. Estimated density of midges (Chironomidae; number per square meter, ± 1 standard error) by study area, weighted by area of strata. Horizontal line indicates grand mean.

Pepin in Pool 4 during the 1980s. Subsequently, the population declined in 1988 following a drought period. In 1926, the Mississippi River from St. Paul to Lock and Dam 3 had dissolved oxygen levels less than 1 mg/L. By 1987,

dissolved oxygen levels had rebounded to 7 mg/L or greater (Johnson and Aasen 1989).

Carlander et al. (1967) showed how dynamic year-to-year mayfly populations were in Pool 19. They estimated pool populations of 3.6 billion

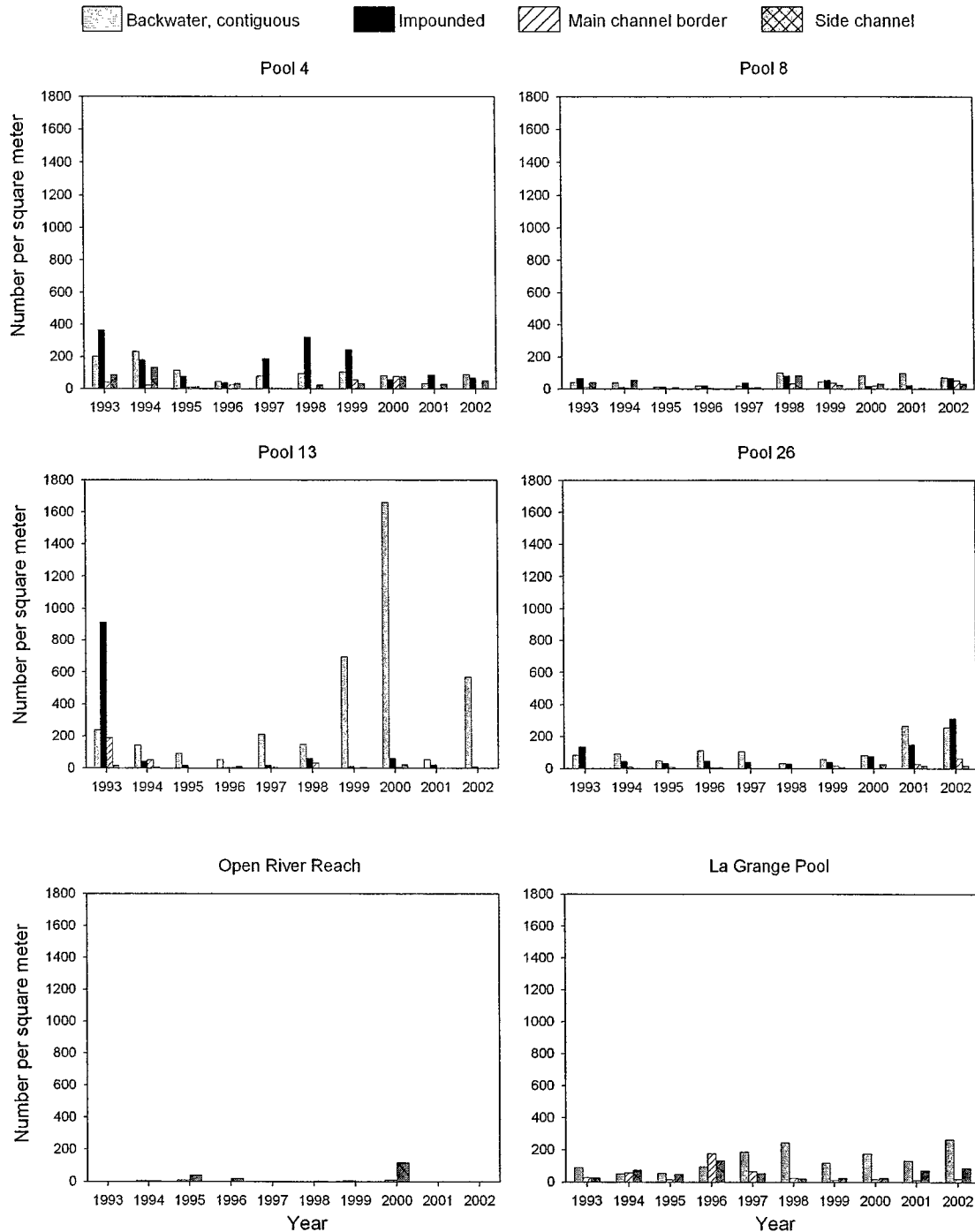


Figure 14. Mean density of midges (Chironomidae; number per square meter) by study reach and aquatic strata. Impounded area for Pool 4 is Lake Pepin, a Tributary Delta Lake.

in 1959 to 23.6 billion in 1962. Carlander et al. (1967) found larval mayfly densities ranging from 0 to 1,292 m^{-2} in June.

Fingernail clams have also experienced boom-and-bust cycles in abundance. Gale (1969) reported fingernail clam population densities

for Pool 19 of more than 5,000 m^{-2} . Fingernail clam populations in several backwater lakes in Pool 9 varied from 631.8 m^{-2} in 1976 to 11.3 m^{-2} in 1989. Consequently increasing to 78.0 m^{-2} in 1990 (Eckblad and Lehtinen 1991). Pool 9 densities reached more than 1,000 m^{-2} in the fall

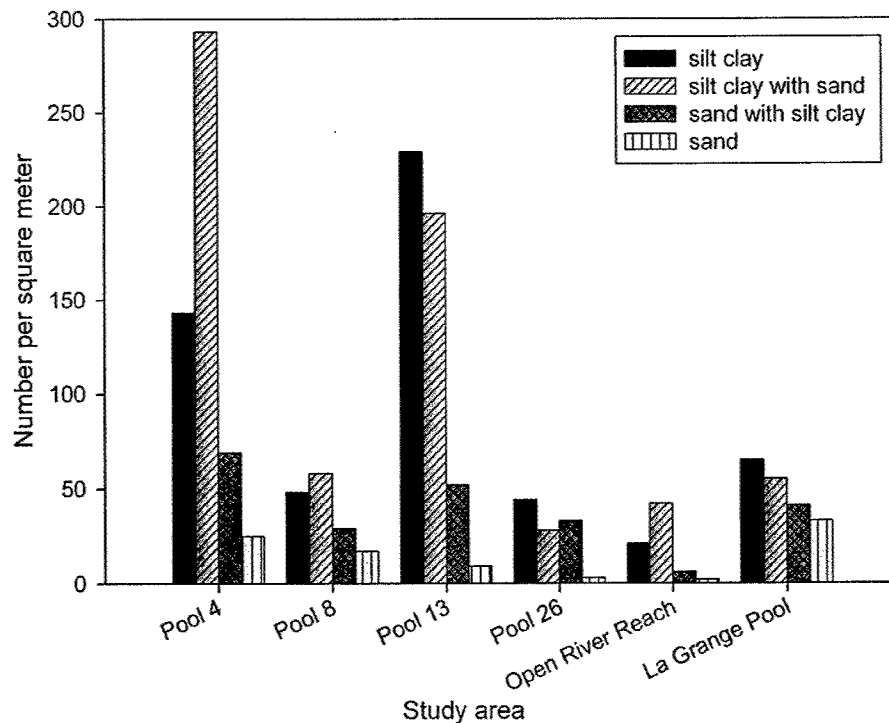


Figure 15. Estimated mean density of midges (Chironomidae; number per square meter) by predominant substrate type, weighted by areas of strata. Because of small sample sizes, substrates defined as clay were combined with the silt clay category and gravel rock with the sand category. All years combined (1993–2002).

of the year (Eric Nelson, U.S. Fish and Wildlife Service, personal communication). From 1992 to 1998, there were extremely low densities of fingernail clams in Pool 8; in 1999 they rebounded to densities well above the 10-year mean (Figure 10). Especially high densities of fingernail clams (2,596 m^{-2}) were found in Pool 13 in 1993 and then collapsed to 87 m^{-2} in 1997. Wilson et al. (1995) reported that in 1985 fingernail clam densities averaged 30,000 m^{-2} in Pool 19. By 1990, no fingernail clams were found. In recent years, peak densities have rebounded to about 50,000 m^{-2} in Pool 19 (Rick Anderson, Western Illinois University, personal communication).

Fingernail clam populations were abundant in the Illinois River before the 1950s (Mills et al. 1966). Paloumpis and Starrett (1960) found fingernail clams extremely abundant in Lake Matanzas (La Grange Pool; 212 m^{-2}) in 1952. By 1953, they had disappeared from the lake. Similar declines were seen in Lake Chautauqua and Quiver Lake. The densities have never rebounded to those reported for the early 1950s.

Richardson (1921) took benthic samples at Lake Matanzas in 1915 and found no *Hexagenia* mayfly nymphs and 225.7 m^{-2} fingernail clams in samples with depths between 2 and 2.6 m with no vegetation, and 5.5 m^{-2} *Hexagenia* and 52.9 m^{-2} fingernail clams in samples with depths of 0.6 to 1.8 m and some vegetation at all sites. Richardson (1921) also took samples in middle Quiver Lake and found *Hexagenia* densities less than 0.5 m^{-2} in 1914 and 1915 and fingernail clam densities of 42.0 m^{-2} in 1914 and 0.8 m^{-2} in 1915. On the basis of the LTRMP data, the 10-year mean density of mayflies and fingernail clams in Quiver Lake ($N = 30$) was 19 and 16 m^{-2} ; respectively. Lake Matanzas ($N = 89$) had 10-year mean densities of 4 m^{-2} mayflies and 1 m^{-2} fingernail clams.

Midges can constitute a large portion of the benthic community (Eckblad 1986). However, few studies have examined the abundance and distribution of midges on the UMRS. Hornbach et al. (1993) found midge densities ranged from 4 to 5,000 m^{-2} in a backwater lake in Pool 2. Midge densities in Pool 4 in 1928 were 2,508

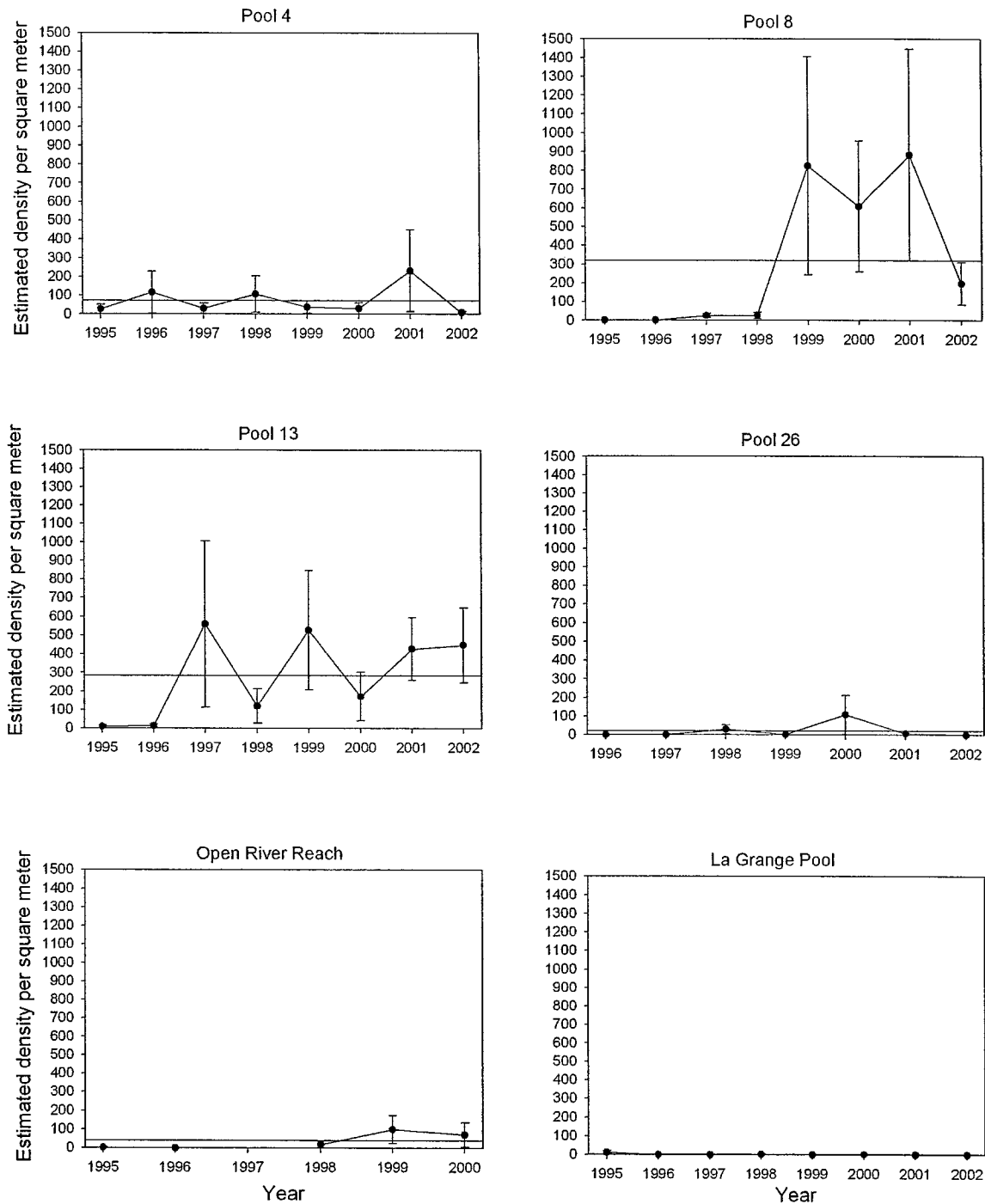


Figure 16. Estimated density of zebra mussels (*Dreissena polymorpha*; number per square meter, ± 1 standard error) by study area, weighted by area of strata. Horizontal line indicates grand mean.

m^{-2} (Johnson 1929). Carlson (1968) reported densities of 0 to 3,052 m^{-2} midges in Pool 19 in 1960–1961.

The densities of mayflies, fingernail clams, and midges reported since the establishment of the LTRMP are well within the ranges reported

by past studies. The fluctuations indicate that these taxa are able to rebound if conditions are right. Data show macroinvertebrate populations are dynamic in the UMRS. The question remains whether various fluctuations seen over the years are entirely natural or are influenced by

anthropogenic factors. Long-term monitoring can develop hypotheses about causal relations; but focused research is also needed to understand these fluctuations fully.

The reason for differences in abundances and percent composition between study areas, particularly Pools 4, 8, and 13 compared with Pool 26, Open River Reach, and La Grange Pool is not known at this time. Possibilities range from differences in substrate, chlorophyll levels, dissolved oxygen levels, discharge levels, or temperatures. Continued monitoring and continued analyses (i.e., integration of macroinvertebrate data with water quality data) are needed to address these differences.

Although LTRMP data yield adequate mean estimates for the study areas, few similar comprehensive inventories were made in the past; therefore, direct comparisons to other studies are difficult. Some studies suggest that mayfly and fingernail clam densities have been declining (Eckblad 1991; Wilson et al. 1995). The results from the stratified random sampling of the LTRMP over the past 10 years suggest that relatively low densities throughout the UMRS could be the rule rather than the exception. The apparent conflict of findings is probably due in part to differing purposes and spatial scopes of the studies. Focused studies are often designed to quantify change—often already under way—in a localized area known for its value as a source for macroinvertebrates and considered at risk because of some destructive event or activity.

Declines in macroinvertebrate densities indicated in the localized studies are a cause for concern because of the value of the UMRS macroinvertebrate community as a source of food for fish and waterfowl. Tyson and Knight (2001) found that benthic invertebrate production played a role for increases in growth and recruitment of yellow perch. Pumpkinseed (*Lepomis gibbosus*) and golden shiner (*Notemigonus crysoleucas*) relative weight has also been correlated with macroinvertebrate biomass (Liao et al. 1995). Mills et al. (1966) reported a decline in the number of fingernail clams that coincided with a similar decline in the number of diving ducks using the Illinois River. Fingernail clam densities in Mississippi River, lower Pool 8, have been relatively low from 1992 to 1997 (0–211.5 m⁻²).

However, fingernail clam densities began to increase in fall 1998 (U.S. Fish and Wildlife Service/U.S. Geological Survey, unpublished data) corresponding with an increase in diving-duck use (Figure 17).

We did not detect any obvious linear trends among mayflies and midges across study areas. However, a positive trend in fingernail clams was observed in Pool 8 (Table 3). Gray et al. (*in press*) reported mean fingernail clam counts were negatively associated with inorganic suspended solid levels in Pool 8. This association seems to reflect substantial decreases in inorganic suspended solid levels (beginning 1998) and increases in mean fingernail clam densities (beginning the following year, 1999).

Differences in mayfly, fingernail clam, and midge abundances among study areas were detectable (Table 3). Canfield et al. (1998) also found there was an order of magnitude in differences of macroinvertebrate abundance values between Pools 1 and 26. While this in itself is important information, a more focused consideration is “Why are the study area taxa abundances different?” We have begun to address this issue through modeling.

Modeling efforts under the LTRMP macroinvertebrate component began in 2002. The reasons for modeling the macroinvertebrate data include quantifying differences by pools or aquatic areas (“status”), estimating temporal trends within pools or aquatic areas (“trends”), and exploring associations between macroinvertebrate densities and environmental factors. These modeling efforts brought many insights into macroinvertebrate dynamics on the river that will be published elsewhere but are summarized in Table 5.

The modeling work stems from the management focus of the LTRMP. Resource managers are concerned with the abundance of mayflies and fingernail clams as they relate to migratory waterfowl and a number of game and sport fish including shovelnose sturgeon, walleye, and bluegills. Managers are interested in whether long-term changes in the UMRS—whether natural or anthropogenic in origin—might lead to changes in mayfly and fingernail clam abundances in the UMRS. Once macroinvertebrate abundance and distribution

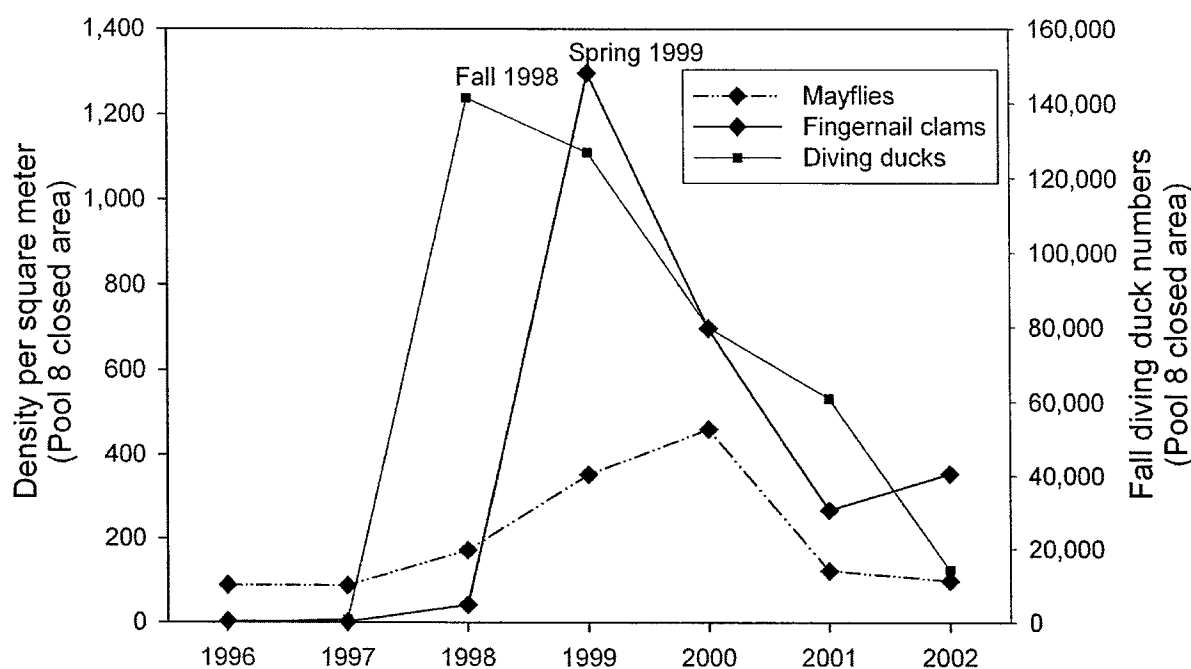


Figure 17. Mean densities of mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and diving ducks from areas of Pool 8 closed to waterfowl hunting, 1996–2002. Duck numbers were estimated in fall by the U.S. Fish and Wildlife Service. Macroinvertebrate numbers were estimated in spring and represent the availability of macroinvertebrates as food for ducks during the previous fall.

patterns are better understood, management actions can be undertaken. Of major interest to river managers is the negative correlation of inorganic suspended solids with fingernail clam density. This relation suggests that management actions taken to reduce inorganic suspended solid levels could increase fingernail clam density. This finding is also an example of a productive integration of information across LTRMP components (water quality and macroinvertebrates).

Similar to macroinvertebrate densities on the UMRS, many biotic components in diverse aquatic ecosystems exhibit high temporal variability (Gido et al. 1997; Bunn and Davies 2000; Dunham et al. 2002; Quist et al. 2003). Much of the year-to-year variability seen in the target taxa collected by the LTRMP is actual change and not error variance. Macroinvertebrates with annual or semiannual life cycles can exhibit substantial change when measured annually. Macroinvertebrate productivity, like many biotic variables, is

strongly contingent upon a number of biotic and abiotic factors; therefore, large annual variations are expected. However, even with this variability, the LTRMP macroinvertebrate sampling yields adequate power to detect long-term trends (http://www.umesc.usgs.gov/ltrmp/power_plots.html). Variable data such as the LTRMP data are well suited for long-term monitoring to help understand processes and patterns (Strayer et al. 1986; Franklin 1988; McEachern 2000). Information on the population status and trends of macroinvertebrates is needed to properly manage and understand the wildlife and fisheries of the UMRS that depend on macroinvertebrates for food.

Summary

This report documents 11 years of macroinvertebrate monitoring (1992–2002) on the UMRS. Abundances of the target taxa were highly variable over the study years; however, they do fall within the range of

Table 5. Modeling efforts on the Long Term Resource Monitoring Program macroinvertebrate data undertaken by the U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin.

Modeling project	Model objectives	Model predictors	Major findings
Mayflies (Ephemeroidea)— Pool 13	<ol style="list-style-type: none"> 1. Evaluate distributional assumptions suitable for modeling aquatic macroinvertebrates 2. Evaluate habitat predictors of mayfly counts 	<ul style="list-style-type: none"> • Water depth (summer and winter) • Water velocity • Fetch • Minimum discharge, August and September previous year • Maximum spring discharge before sampling • Maximum fall discharge, previous year • Annual peak discharge (expected to reoccur at a 10-year interval), previous year • Substrate • Submersed vegetation 	<ol style="list-style-type: none"> 1. Mayfly counts best fit by the negative binomial distributional assumptions. 2. Best habitat predictor of mayflies in Pool 13 is substrate; associations with vegetation vary substantially from year-to-year (probably because of variations in temperature and river stage).
Mayflies—Pool 8	Model unsuitable habitat using zero-inflated modeling techniques	<ul style="list-style-type: none"> • Strata • Substrate categories 	Unsuitable habitat strongly associated with combinations of high current and sandier substrates. This confirms previous assumptions and provides quantitative evidence for resource managers and for sampling designs.
Fingernail clams (Pisidiidae)— Pools 4, 8, and 13 in backwaters and impounded strata	Model fingernail clam counts at sampling and aquatic area scales	<ul style="list-style-type: none"> • Discharge, spring maximum • Discharge, minimum • Temperature • Substrate (local and strata) • Chlorophyll <i>a</i> • Volatile and inorganic suspended solids 	Fingernail clam density associated with substrate categories and, at strata scale, with inorganic suspended solids. For Pool 8, inorganic suspended solids association reflects substantial changes in inorganic suspended solids levels (beginning 1998) and in mean clam densities (beginning 1999). Weak association also observed across backwater regions for spring maximum discharge.

abundances recorded in past studies. Variation in abundances is greater spatially (among study areas) than temporally (among years). The northern most study areas (Pools 4, 8, and 13) have greater abundances of the target taxa than the more southern study areas (Pool 26, Open River Reach, and La Grange Pool). The macroinvertebrate component was reviewed to evaluate the usefulness of these data to managers and to suggest future work under this component. Results will be published separately (Sauer, *in press*).

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Appendix A. Life Histories of Target Taxa

Life histories of the target organisms chosen for Long Term Resource Monitoring Program (LTRMP) macroinvertebrate sampling have been well documented (Hunt 1953; Fremling 1960; Pennak 1978; Thorp and Covich 1991). Factors affecting the various life-history stages can affect abundance and distribution. Following are a few main points regarding the life history of the target taxa.

Mayflies: Class, Insecta; Order, Ephemeroptera; Family, Ephemeridae, Hexagenia spp.

Mayflies are unique insects in that they have two adult stages (subimago and imago) along with an aquatic nymph and egg stage. This life-history strategy emphasizes the importance of mayflies to the aquatic (e.g., fish, predacious insects, and waterfowl) and terrestrial (e.g., bats, swallows, adult dragonflies) food web because they are accessible to a variety of predators throughout their life cycle.

Typically, adult female mayflies (Figure A-1) lay two egg sacs containing on the average of 4,000 eggs. The egg sacs burst when they enter the water and the individual eggs immediately disburse. Eggs are laid throughout the summer, but more intensively 1–2 days following a major hatch. Mayfly eggs hatch in 14–20 days (Hunt 1953). Several factors including adult fecundity, water temperature, water flow, and predation can

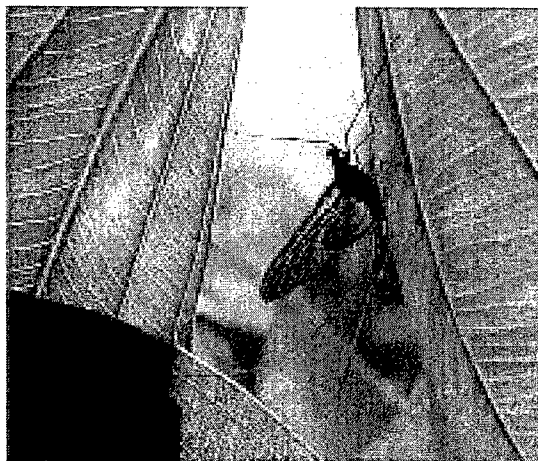


Figure A-1. Adult mayfly (*Hexagenia* spp.)

affect the distribution and abundance of eggs that hatch into aquatic nymphs. Growth is rapid during this stage until the water temperature falls to about 8.8°C. Studies have shown that growth essentially ceases overwinter (Hunt 1953; Brittain 1990).

Nymphs of *Hexagenia* spp. construct a U-shaped burrow in the sediment (Figure A-2). They consume algae and plant debris, deriving nutrients from organic material in the sediment along with digesting some bacteria (Hunt 1953). The character of the bottom sediment is the most essential factor in describing the abundance and distribution of mayfly nymphs (Lyman 1943; Hunt 1953; Ericksen 1968; Wright and Mattice 1981). However, many other factors come into play including dissolved oxygen levels, predation, sedimentation, water temperature, sediment contamination, and flow (Hunt 1953; Mauck and Olson 1977; Clements and Kawatski 1984; Rasmussen 1988; Koel and Stevenson 2002).



Figure A-2. Nymph of *Hexagenia* spp. in a U-shaped burrow. Permission to reprint photograph by courtesy of Dr. Calvin Fremling.

As the nymph approaches emergence, it leaves the burrow and swims to the surface. Nymphs hatch into subimagos when the water temperature reaches 14 to 18°C (Fremling 1973) taking 10–95 sec to emerge (Hunt 1953). The nymphs are susceptible to predation as they enter the water column. Adult stages are winged, short-lived, and do not feed. The mature adult (imago) emerges when the subimago moults. The role of the imago is mating and egg-laying (Fremling 1973). Whereas the large synchronous hatches

of mayflies can cause short-lived problems for humans, their return is a sign of good water quality and is important to the wildlife food chain. Because of its size, *Hexagenia* spp. may be the most important invertebrate to fish and waterfowl in the Upper Mississippi River System (Gale 1969). Mayflies are consumed by 9 of 13 fish of management interest to the LTRMP partners (Hunt 1953; Hoopes 1960; Ranthum 1969).

*Fingernail Clams: Class, Bivalvia;
Order, Veneroida; Family, Pisidiidae,
Sphaerium spp., Musculium spp.,
Pisidium spp.*

One important aspect of fingernail clam (Figure-3) life history is they are hermaphroditic. That is, they have both male and female reproductive organs with internal fertilization and the development of young exists in brood sacs (Gale 1973; Heard 1977; Anderson et al. 1978). Heard (1977) reported fingernail clams can have up to two broods a year. Fingernail clams have been reported to complete their life cycle in as little as 33 days. They are nonselective filter feeders consuming phytoplankton with gut contents having more green algae than diatoms. Ingestion stops at 2–4°C. Fingernail clams can remain buried in the sediment for up to a month and newborn clams are able to survive up to 2 weeks in anaerobic conditions (Gale 1976). Factors affecting the abundance and distribution of fingernail clams include dissolved oxygen

levels, unionized ammonia, predation, water temperature, sediment contamination, and flow (Anderson et al. 1978; Sandusky and Sparks 1979; Sparks 1980).

Fingernail clams are important to the nutrient dynamics of an ecosystem through excretion and biodeposition of feces and pseudofeces (Vaughn and Hakenkamp 2001). A number of fish and wildlife include fingernail clams in their diet. At certain times of the year in Pool 19, fingernail clams made up 100% of the diet (by volume) of common carp (*Cyprinus carpio*) and smallmouth buffalo (*Ictiobus bubalus*) and 10–70% of black bullhead (*Ameiurus melas*), gizzard shad (*Dorosoma cepedianum*), pumpkinseed (*Lepomis gibbosus*), bigmouth buffalo (*Ictiobus cyprinellus*), freshwater drum (*Ictiobus cyprinellus*), and bluegill (*Lepomis macrochirus*; Jude 1968, 1973; Ranthum 1969). Fingernail clams are consumed by 4 of 13 fish of management interest to LTRMP partners (Hunt 1953; Hoopes 1960; Ranthum 1969). In spring, fingernail clams can make up to 85–95% of the diet (by volume) of lesser scaup (*Aythya affinis*), ring-necks (*A. collaris*), canvasbacks (*A. valisineria*), goldeneyes (*Bucephala clangula*), and ruddies (*Oxyura jamaicensis*; Thompson 1973).

*Midges: Class, Insecta; Order, Diptera;
Family, Chironomidae*

Midges are sometimes referred to as blood worms (Figure A-4). The red coloration is

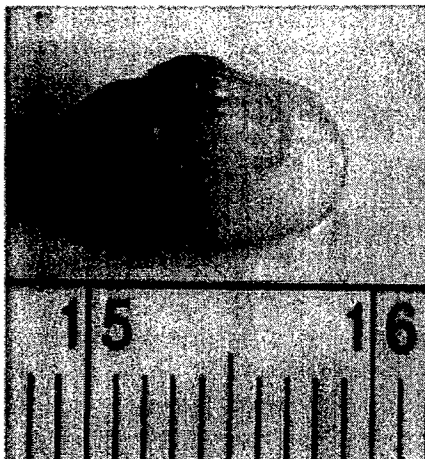


Figure A-3. Fingernail clam (*Pisidiidae*)



Figure A-4. Larval midge (*Chironomidae*)

because of the presence of hemoglobin that stores oxygen. This allows them to live in areas with limited oxygen conditions or areas of high organic pollution. Like other dipterans, chironomids have four life stages: egg, larva, pupa, and adult. Female midges deposit a gelatinous mass of eggs on the water surface or attach it to submersed vegetation. After hatching the larvae pass through four instars before pupating. The duration of the larval stage may be from 2 weeks to several years; depending mostly on temperature. Larvae feed primarily on algae and other organic debris. The pupal stage lasts no more than a few days (Mandaville 1999).

Adult chironomids are minute with generally reduced mouthparts. Adults often emerge, simultaneously, in huge numbers, and proceed to form vast mating clouds (Mandaville 1999). Similar to mayflies, the large synchronous hatches of midges can cause short-lived problems for humans; however, they are an important component of the river food web.

A number of fish use midges in their diets including common carp, redhorse (*Moxostoma* spp.), and channel catfish (*Ictalurus punctatus*). Gadwall (*Anas strepera*), red-heads (*Aythya americana*), and wood ducks (*Aix sponsa*) all use midges in their diets (Ringelman 1990; Drugger and Fredrickson 1992; Custer 1993). Factors affecting the abundance and distribution of midges include predation, water temperature, competition, and food availability (Pinder 1986).

Zebra Mussels: Class, Bivalvia; Order, Veneroida; Family, Dreissenidae, Dreissena polymorpha

The zebra mussel (Figure A-5) is a freshwater bivalve that invaded the Great Lakes about 1986. Zebra mussels first appeared in Lake St. Clair between Lakes Erie and Michigan, possibly from ship's ballast water from the Black Sea region (Nalepa and Schloesser 1992). Aided by current, they rapidly spread downstream and, by human mediation, throughout many other basins. Zebra mussels are considered a nuisance species



Figure A-5. Zebra mussels (*Dreissena polymorpha*)

because they can foul water-treatment and power plants by attaching in large numbers to water intakes using their byssal threads plus they compete for food and space with native mussels.

Broadcast spawning disperses zebra mussel eggs and sperm and spawning can continue over a period of several weeks. As water temperatures rise above 12°C, external fertilization occurs when adult mussels release eggs and sperm into the water column. After fertilization, developing embryos (planktonic veligers) remain in the water column and drift for some distance. The time required to develop from egg to juvenile mussel varies according to water temperature, but averages about 2 weeks. They are able to spread so quickly because of their highly prolific reproduction—a mussel can lay more than 40,000 eggs in a reproductive cycle and up to 1 million in a spawning season—and the ease with which they, during their planktonic larval stages, can be transported to new areas, as well as their ability to attach to boat hulls. They may be found at high densities and filter large volumes of water, removing suspended particulate matter. Zebra mussels are tolerant of a wide range of environmental conditions. (Nalepa and Schloesser 1992; D'Itri 1997). Studies have shown that zebra mussels can be eaten by fish with pharyngeal teeth, such as the freshwater drum (*Aplodinotus grunniens*; French and Bur 1992), and diving ducks, such as scaup (Custer and Custer 1996; Petrie and Knapton 1999).

Asiatic Clam: Class, Bivalvia; Order, Veneroida; Family, Corbiculidae, Corbicula spp.

The Asiatic clam (Figure A-6) is a freshwater bivalve that invaded the northwest United States in the late 1800s. The accidental spread of Asiatic clams by boat bilge water, aquarium hobbyists, and fishing bait along with migrating waterfowl are possible pathways of introduction to other areas of the United States. Similar to zebra mussels, Asiatic clams are considered a nuisance species because they can foul water-treatment and power plants by attaching in large numbers to water intakes using their byssal threads plus they compete for food and space with native mussels (McMahon 1983).

The clams are highly prolific with larval releases reaching 400 larvae/clam/day. Unlike zebra mussels, the larvae are not typically free-swimming veligers, but are adapted more for swimming and crawling. Sexes are normally separate; but can be hermaphroditic. On average, Asiatic clams have a life span of 1 to 4 years (Thorp and Covich 1991).

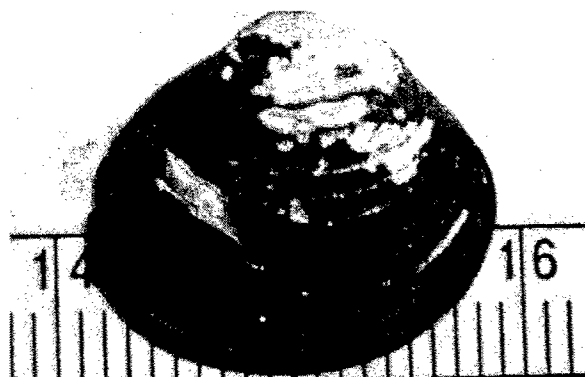


Figure A-6. Asiatic clam (*Corbicula fluminea*)

Asiatic clams may be present at high densities and filter large volumes of water, removing suspended particulate matter. They are tolerant of a wide range of environmental temperatures. (Mattice and Dye 1976). However, their northward expansion is probably limited by low temperatures in winter to where they are associated with warmwater discharges (McMahon 1983). Some fish and diving ducks have been recorded eating Asiatic clams (McMahon 1983; Hoope et al. 1986; Hendricks 1998).

Appendix B. Macroinvertebrate Sampling Methods Used by Various Researchers at Historical (Fixed) Sites in the Upper Mississippi River System

The following studies were used for the selection of historical sites that were resampled by the Long Term Resource Monitoring Program:

Pool 4—North Star Research Institute (1973)

- 2 Ponar grabs collected and contents pooled
- No. 40 soil sieve size (425 μm)
- Sampling period spring and summer 1973
- 4 sites resampled for the Long Term Resource Monitoring Program (LTRMP)

Pool 8—Elstad (1977)

- 1 dredge haul (0.023 m^2)
- No. 30 sieve size (595 μm)
- 41 sampling areas chosen, 2 main channel areas, and 39 adjacent waters; transects run east–west
- Sampling period June 15 to July 15, 1975
- 16 sites resampled for the LTRMP

Pool 8—Brewer (1992)

- 2 Petite Ponar dredge hauls combined (0.046 m^2)
- No. 30 sieve size (595 μm)
- Resampled Elstad's sites
- Sampling period June 21 to July 13, 1990
- 16 sites resampled for the LTRMP

Pool 13—Hubert et al. (1983)

- 1 Peterson dredge (0.092 m^2); 3 replicates at each site pooled
- Sieve (0.5 mm)
- 6 habitat types chosen for sampling (main channel, main channel border, tailwater, side channel, lakes, and sloughs)
- Sampling period February 26 to March 6, 1983
- 7 sites resampled for the LTRMP

Pool 26—Seagle and Zumwalt (1981)

- 1 Ponar grab (0.052 m^2)
- No. 30 sieve size (595 μm)
- Above wing dam
- Sampling period April 1981
- 1 site resampled for the LTRMP

Pool 26 - Colbert et al. (1975)

- 2 Peterson or Ponar grabs
- No. 30 sieve size (595 μm)
- 4 habitat types sampled (main channel, side channel, main channel border, main channel border influenced by dikes); transects run
- Sampling period July 2–12, 1974
- 6 sites resampled for the LTRMP

Open River Reach—Emge et al. (1974)

- 2 Peterson dredge hauls collected and contents pooled (0.16 m^2)
- No. 30 sieve size (595 μm)
- Side channels and main channel border sampled
- Sampling period late June 1972 or July 1973
- 18 sites resampled for the LTRMP

La Grange Pool—Paloumpis and Starrett (1960)

- Ekman dredge 6 \times 6 inches
- No. 30 sieve size (595 μm)
- Lake Matanzas and Quiver Lake; 1952–1954
- 22 sites resampled for the LTRMP

La Grange Pool - Anderson (1977)

- Ekman dredge 6 \times 6 inches
- No. 30 sieve size (595 μm)
- August through September 1975
- 4 sites resampled for the LTRMP

Location of historical (fixed) sites sampled by various researchers and resampled by the Long Term Resource Monitoring Program (Figures B-1 to B-6).

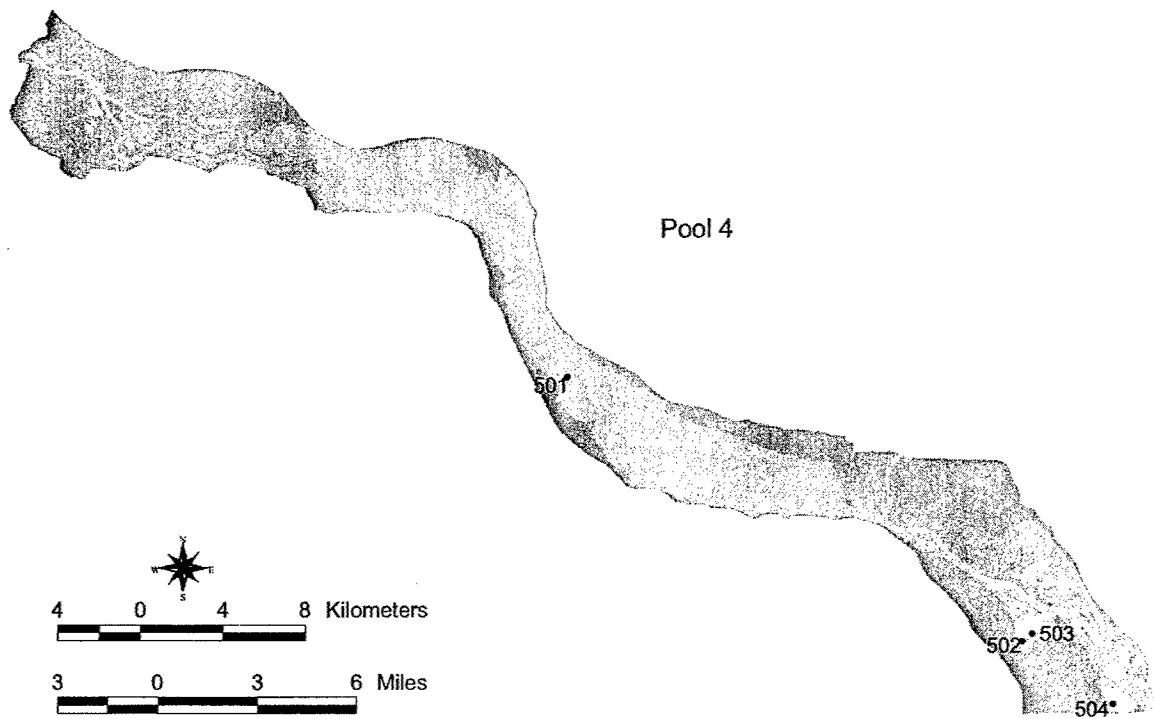


Figure B-1. Location of historical (fixed) sites 501–504 in Pool 4, Upper Mississippi River.

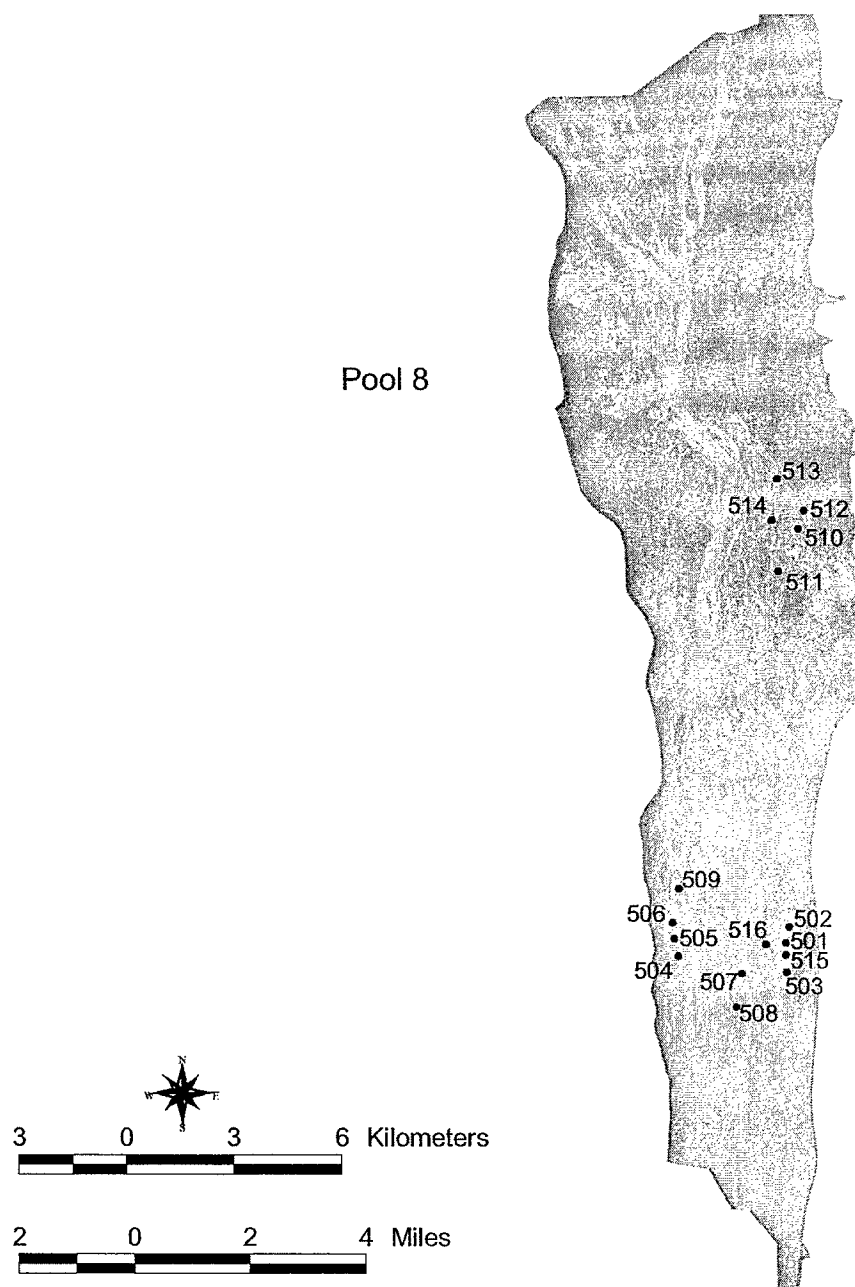


Figure B-2. Location of historical (fixed) sites 501–516 in Pool 8, Upper Mississippi River.

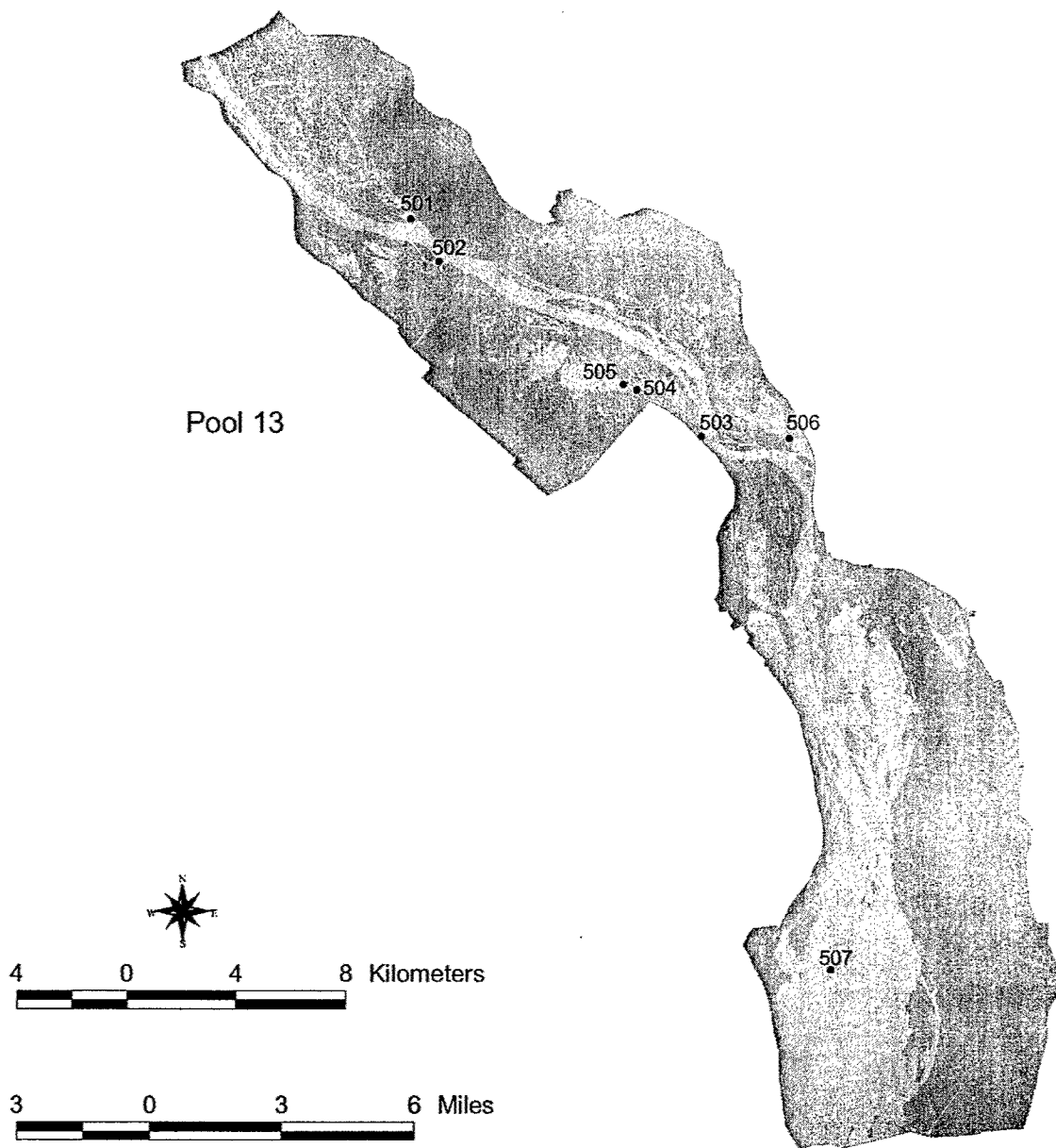


Figure B-3. Location of historical (fixed) sites 501–507 in Pool 13, Upper Mississippi River.

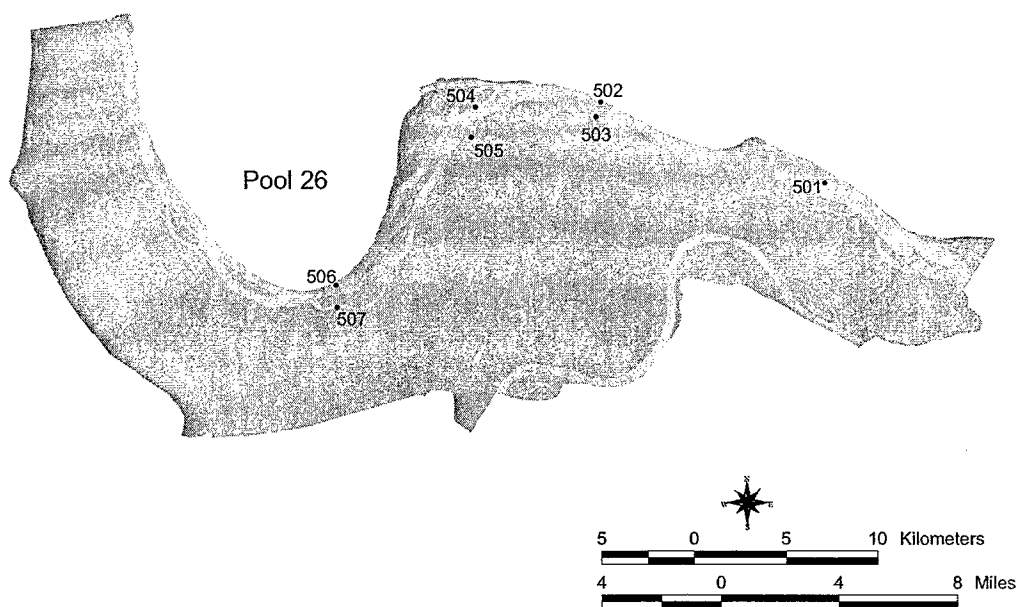


Figure B-4. Location of historical (fixed) sites 501–507 in Pool 26, Upper Mississippi River.

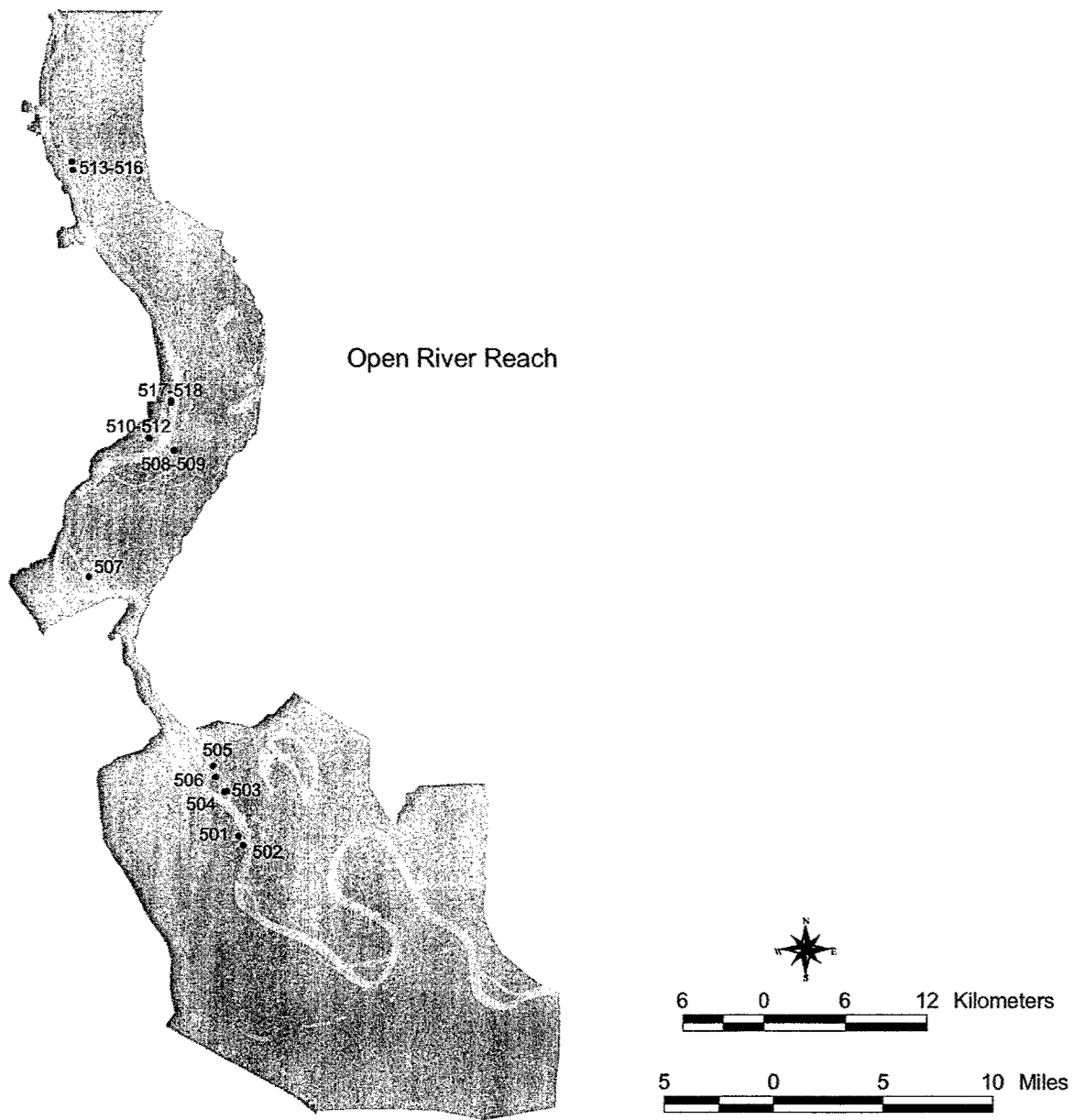


Figure B-5. Location of historical (fixed) sites 501–518 in Open River Reach, Upper Mississippi River.

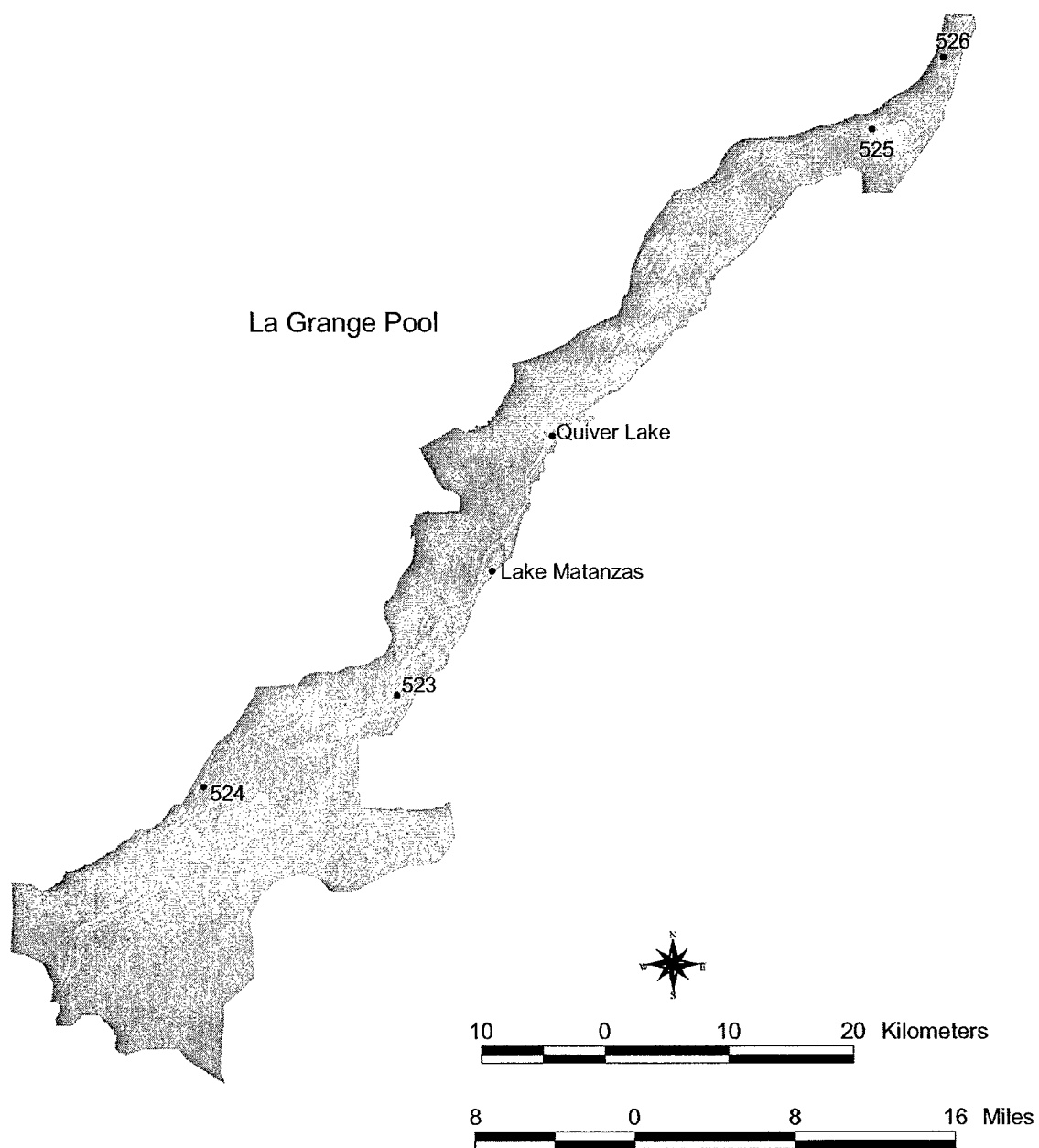


Figure B-6. Location of historical (fixed) sites 523-526 including Quiver Lake and Lake Matanzas in La Grange Pool, Illinois River.

Appendix C. Historical (Fixed) Sample Sites Resampled by the Long Term Resource Monitoring Program

These are sites where benthic samples were previously collected by researchers (Figures C-1 to C-7; see Appendix B).

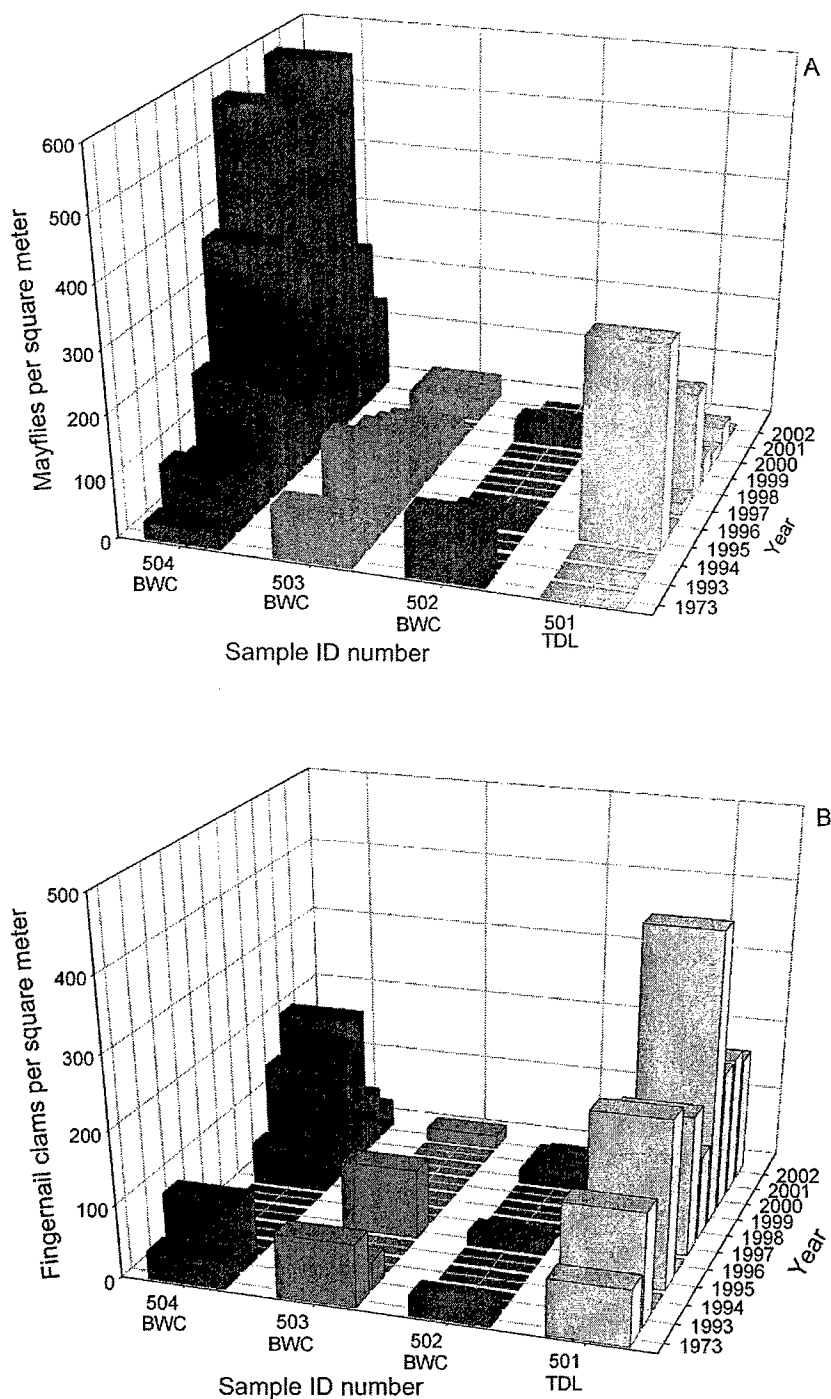


Figure C-1. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at sites 501–504 in Pool 4 of the Upper Mississippi River System (BWC = Backwaters, contiguous; TDL = tributary delta lake). The 1973 data are from North Star Research Institute (1973). The 1993–2002 data are from the Long Term Resource Monitoring Program.

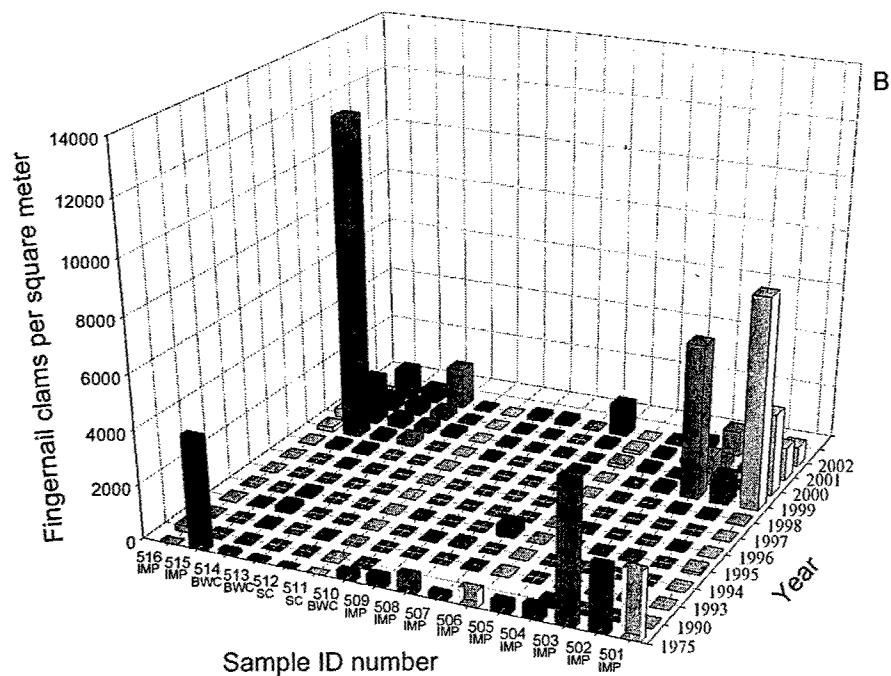
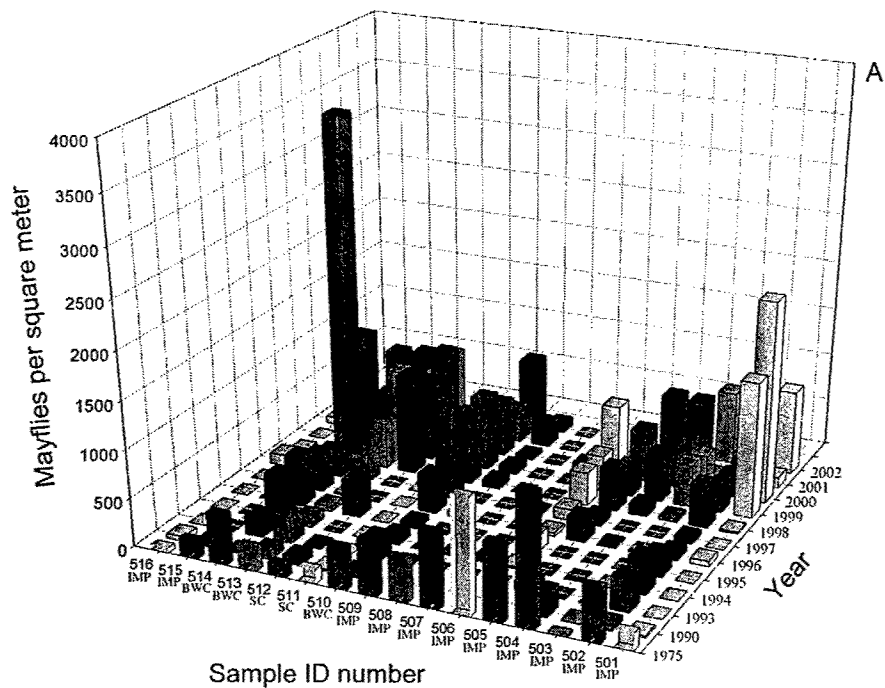


Figure C-2. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at sites 501–516 in Pool 8 of the Upper Mississippi River System (BWC = Backwaters, contiguous; IMP = impounded areas; SC = side channels). The 1975 data are from Elstad (1977) and the 1990 data are from Brewer (1992). The 1993–2002 data are from the Long Term Resource Monitoring Program.

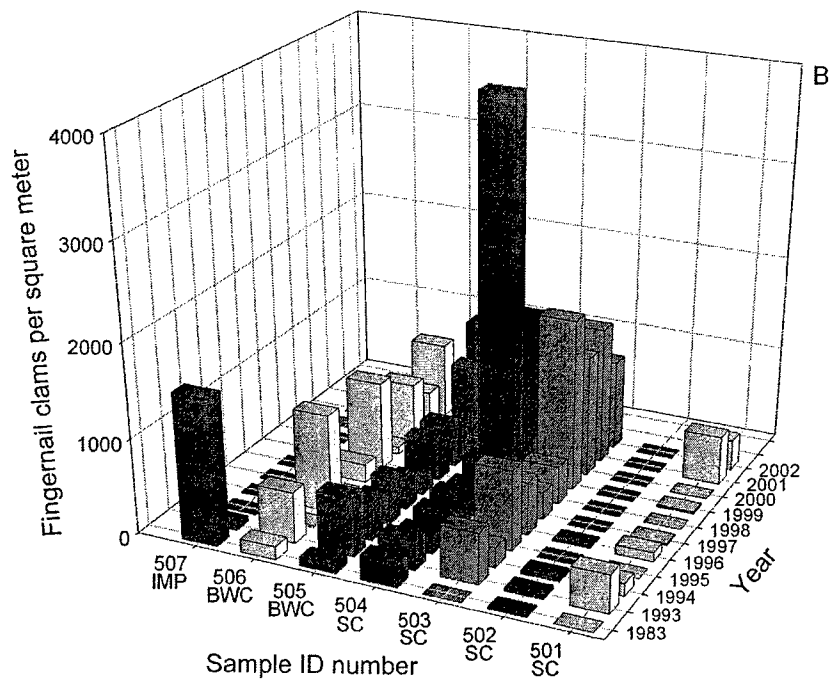
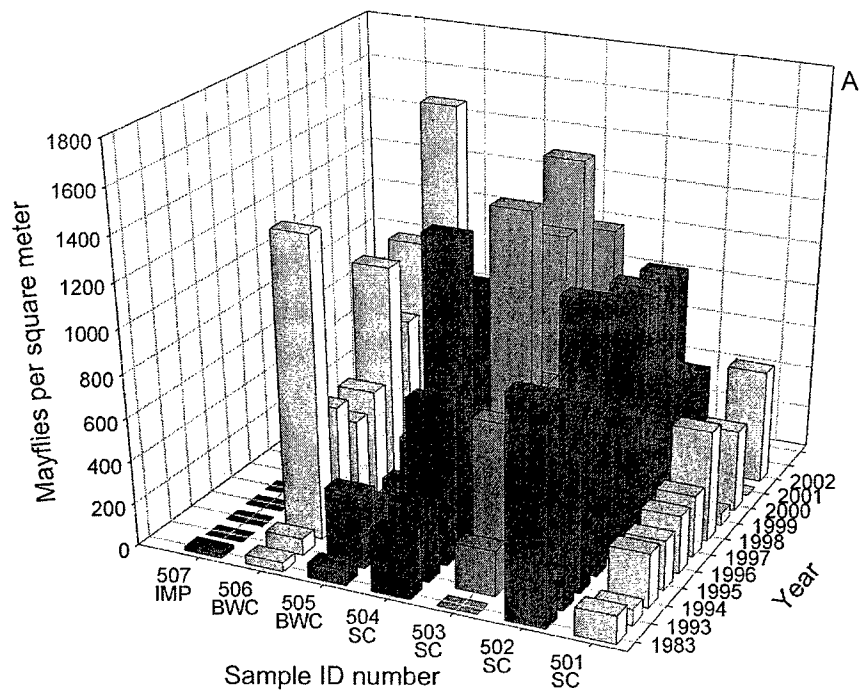


Figure C-3. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at sites 501–507 in Pool 13 of the Upper Mississippi River System (BWC = Backwaters, contiguous; IMP = impounded areas; SC = side channels). The 1983 data are from Hubert et al. (1983). The 1993–2002 data are from the Long Term Resource Monitoring Program.

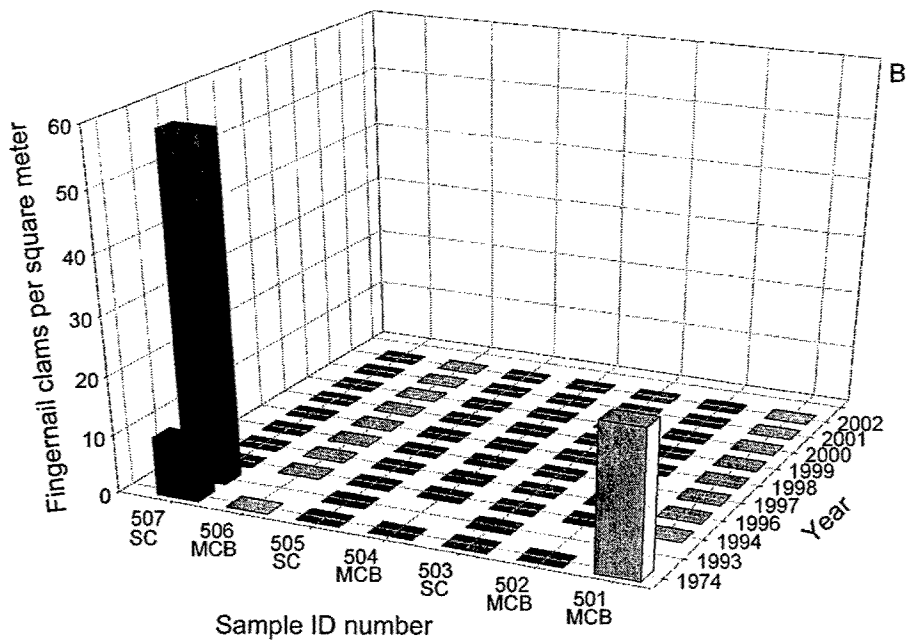
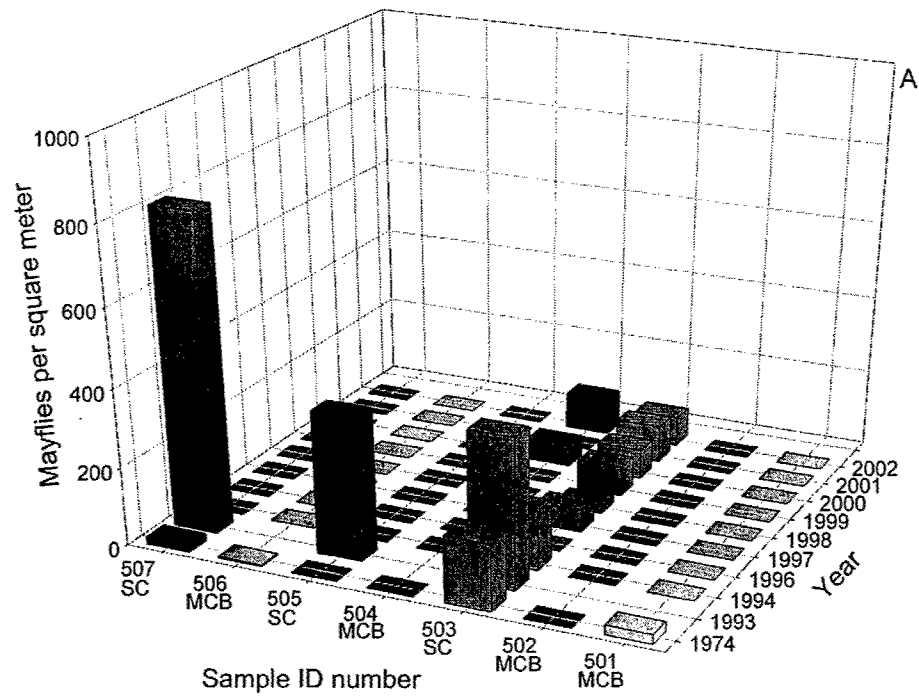


Figure C-4. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at sites 501–507 in Pool 26 of the Upper Mississippi River System (MCB = main channel borders; SC = side channels). The 1974 data (sites 501–503 and 505–507) are from Colbert et al. (1975) and site 504 was sampled in 1981 by Seagle et al. (1982). The 1993–2002 data are from the Long Term Resource Monitoring Program.

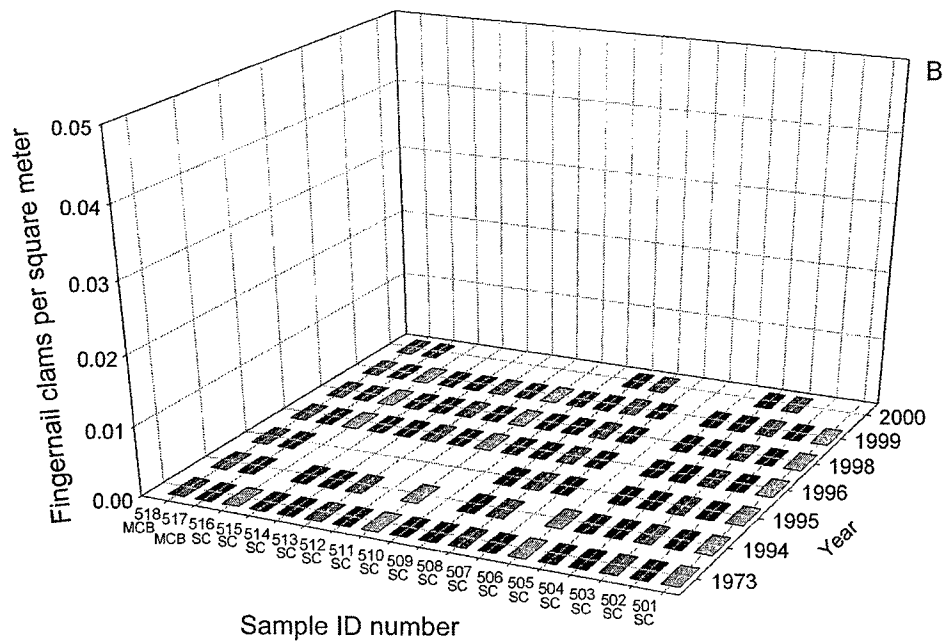
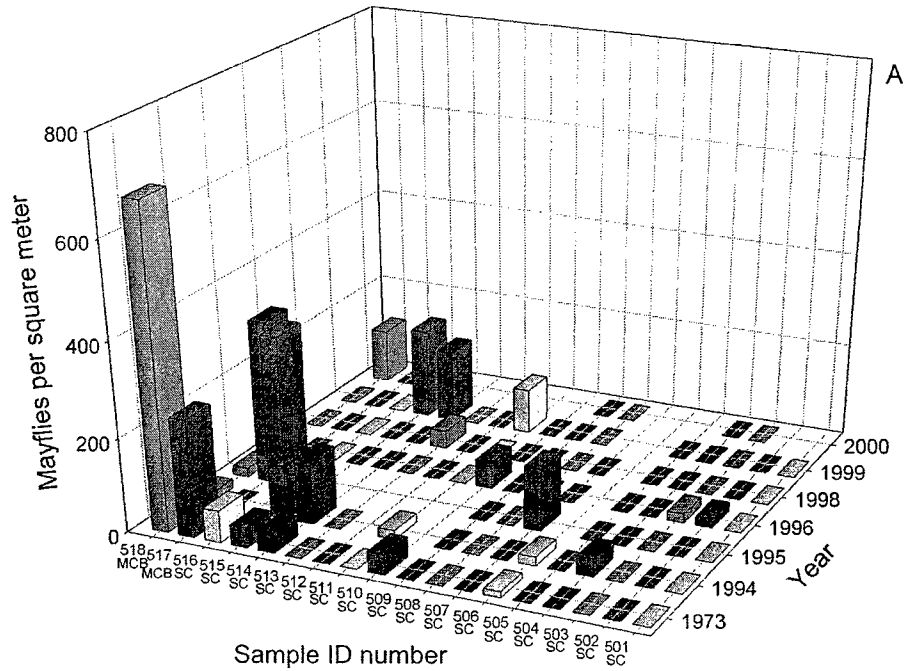


Figure C-5. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at sites 501–518 in Open River Reach of the Upper Mississippi River System (MCB = main channel borders, SC = side channels). The 1973 data are from Emge et al. (1974). The 1994–2000 data are from the Long Term Resource Monitoring Program.

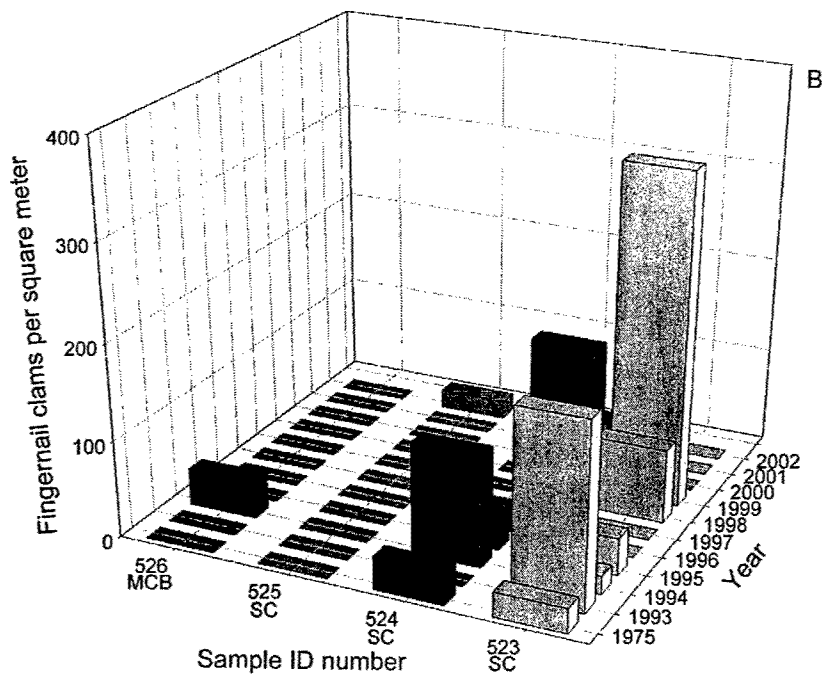
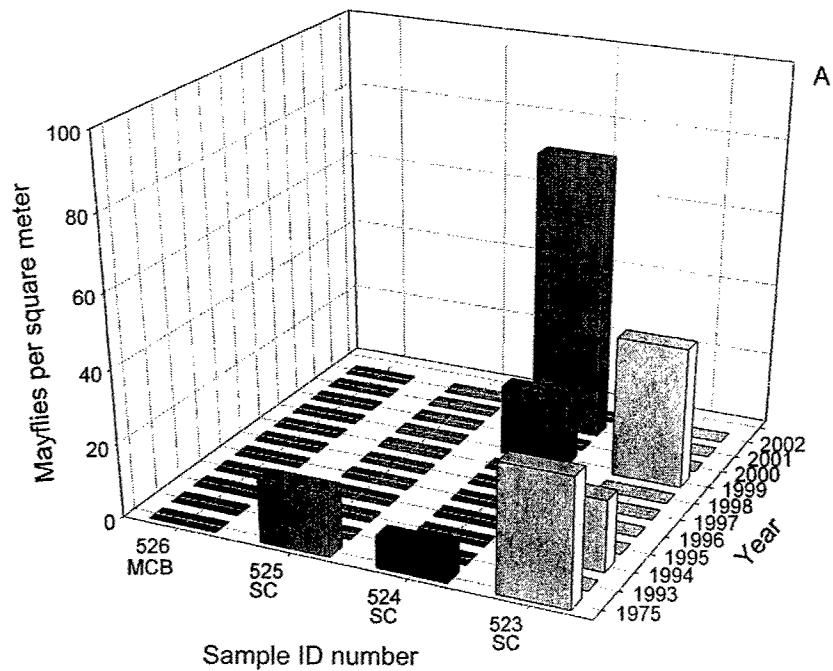


Figure C-6. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at sites 523–526 in La Grange Pool of the Upper Mississippi River System (MCB = main channel borders, SC = side channels). The 1975 data are from Anderson (1977). The 1993–2002 data are from the Long Term Resource Monitoring Program.

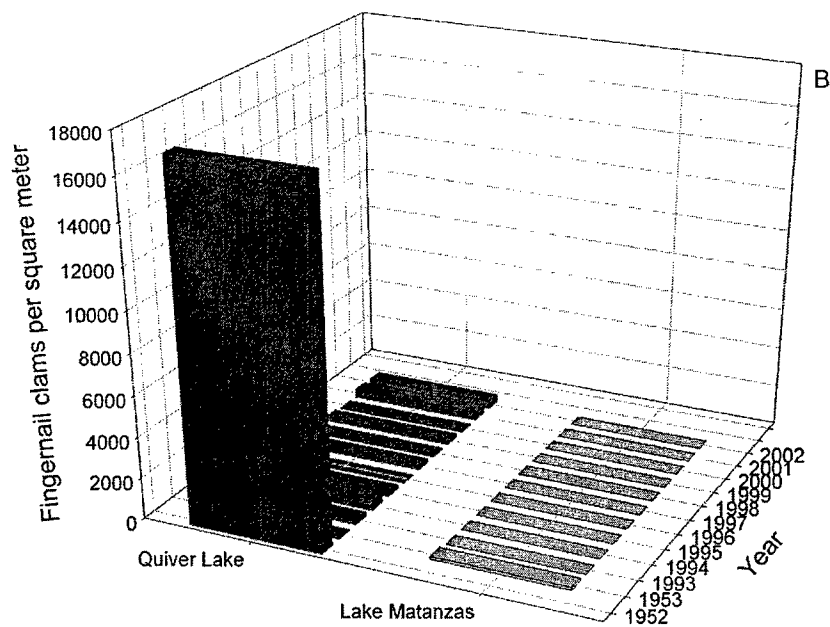
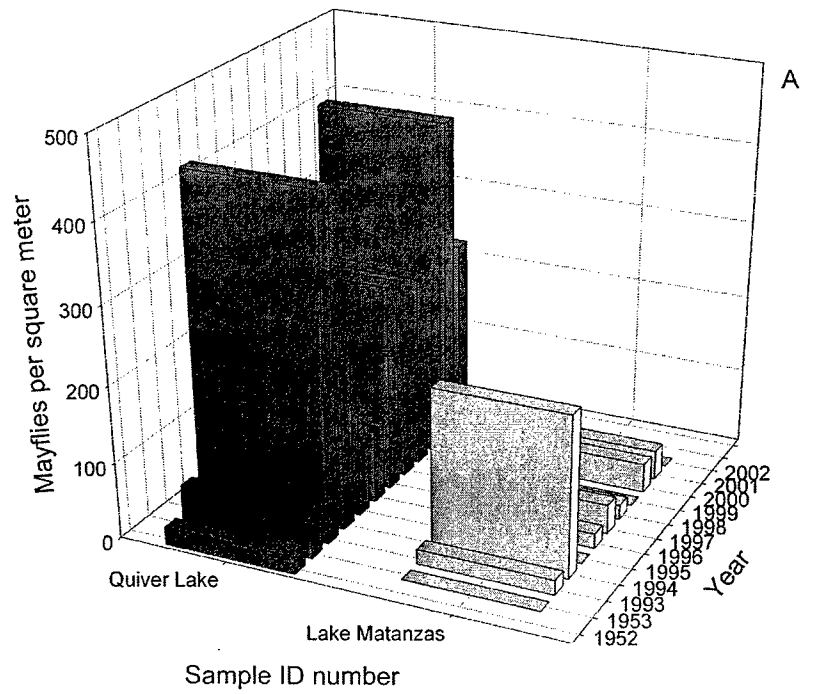


Figure C-7. Abundance of (A) mayflies (Ephemeroptera) and (B) fingernail clams (Pisidiidae) at Quiver Lake and Lake Matanzas of the Upper Mississippi River System. The 1952 and 1953 data are from Paloumpis and Starrett (1960). The 1993–2002 data are from the Long Term Resource Monitoring Program.

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13. ABSTRACT (Maximum 200 words)

In 1992, macroinvertebrate sampling was begun in Pools 4, 8, 13, and 26; the Open River Reach of the Mississippi River; and La Grange Pool of the Illinois River as part of the Long Term Resource Monitoring Program. Long-term monitoring is needed to detect population trends and local changes in aquatic ecosystems. We selected mayflies (Ephemeroptera), fingernail clams (Pisidiidae), and the exotic *Corbicula* species for monitoring. Midges (Chironomidae) were added to the sampling design in 1993 and zebra mussels (*Dreissena polymorpha*) were added in 1995. Sampling was based on a stratified random design and conducted at approximately 125 sites per study area. Mean densities of taxa were weighted by strata for extrapolation. The poolwide estimated mean densities of mayflies, fingernail clams, and midges were all within the range of variation observed historically. Over the last 11 years of sampling, the northern study areas supported the highest densities of the target organisms.

14. SUBJECT TERMS (Keywords)

Benthic aquatic macroinvertebrates, *Corbicula*, fingernail clams (Pisidiidae), Illinois River, Long Term Resource Monitoring Program, mayflies (Ephemeroptera), midges (Chironomidae), Mississippi River, zebra mussels (*Dreissena polymorpha*)

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The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP is to provide river managers with information for maintaining the Upper Mississippi River System as a sustainable large river ecosystem given its multiple-use character. The LTRMP is a cooperative effort by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.

